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DESULPHURISATION OF SHALE OILS,
OIL-SHALE RESOURCES,
and
PRODUCTION OF OIL FROM CANNEL COAL
AND ALLIED MINERALS.

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Issue of Journal. The Journal appears in four parts per sessional volume, viz. in December, February, April and June. A brochure describing the origin, progress and purposes of the Institution, and comprising also the Memorandum and Articles of Association, the By-Laws and Regulations of the Institution, the Library Catalogue to date (with subject index), and the List of Members, was published in September, 1915, to be followed annually by revisions of the Library Catalogue and List of Members.

Members of all classes are entitled to receive these publications free: for additional copies of the Journal they will be charged at the price of five shillings per part, and of the brochures at the prices stated on the wrappers, varying in proportion to bulk.

Changes of Address. It is particularly requested that members notify the Secretary immediately of any change of address; and members are also requested to advise the Parcel-Post Department as well as the Letter Office, of any temporary change of address, as, unless this is done, parcel-post packets will not be re-addressed; but will be returned to the offices of the Institution in London, thus incurring further expense for postage.

To Authors of Papers. Papers should be written in the third person, and the copy should be carefully corrected by the author before it is presented.

All drawings, diagrams or other illustrations should be sent in a fit state for direct photographic reproduction.

All quotations, technical terms, and localisms should be indicated by means of inverted commas.

Foreign weights, measures, and costs should be given whenever possible; and also their English equivalents.

It is suggested that authors append as complete a bibliography of the subject treated as may be possible.

All papers and notes submitted to the Institution are supposed to be original communications unless distinctly stated to be otherwise, in which case the exact reference to the previous publication should be given.

Communications upon papers read at meetings, notices of personal movements, or other matter for which publication is desired in the next issue of the Journal, should be in the hands of the Editor on or before the last day of January, March, May or November as the case may be. Subsequent delivery may be too late for insertion.

The Library. The additions to the Library during the last six months are duly entered in the new Library Catalogue presently going to press, and need not be here set forth. The thanks of the Institution are due to the following donors: A. Campbell; W. H. Dalton; Department of Scientific and Industrial Research; T. Dewhurst; A. E. Dunstan; A. W. Eastlake; Federation of British Industries; E. de Golyer; R. Gray; A. E. Guttentag; E. L. Lomax; B. Redwood; Scientific Societies Conjoint Board; Sinclair Corporation; L. P. Sol; Stanford University, Cal.; Texas Co.; F. B. Thole; United States Bureau of Mines; University of California; University of Pittsburg; W. Whitaker.

Through the kindness of Prof. Brame we have just received a large collection of parts of the Journ. Chem. Soc. and Journ. Soc. Arts from the library of the late Prof. V. B. Lewes, but these will not appear in the Catalogue till a later edition is prepared.

Exchange List.

The following is the list of Institutions, etc., with whom we exchange publications: we shall be happy to extend it in suitable directions.

American Academy of Arts and Sciences.
American Chemical Society.
Australia, High Commissioner.
Canada, Department of Mines, Geological Survey.
" " " " Mines Branch.

Chemical Society (London).
Diesel Engine Users Association.
Gas and Oil Power.
Glasgow Geological Society.
Imperial Institute.
India Geological Survey.
Institute of Chemistry.
Institution of Mechanical Engineers.
Institution of Mining and Metallurgy.
Institution of Mining Engineers.
Iron and Steel Institute.
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Manchester Geological and Mining Society.
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Mining Institute of Scotland.
North of England Institute of Mining and Mechanical Engineers.
North Staffordshire Institute of Mining and Mechanical Engineers.
Oil Age.
Oil and Colour Trades Journal.
Royal Colonial Institute.
Royal Society of Arts.
Shipbuilding and Shipping Record.
Society of Chemical Industry.
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United States Geological Survey.
" " Patent Office.
Yorkshire Naturalists' Union.

The Journal is also forwarded to the British Museum, Copyright Department, to the Patent Office Library, to the University Libraries of Cambridge, Dublin, Edinburgh and Oxford, and to the National Library of Wales, Aberystwith.

Advertisements in the Journal. A limited number of Advertisements of firms interested in the Petroleum Industry may be inserted in the Journal. Application for terms, etc., should be made to the Secretary.

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PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that Members of the Institution send information regarding their movements to the Secretary for insertion under this heading.

Eng. Vice-Admiral Sir G. G. GOODWIN, K.C.B., R.N., and Sir AUBREY STRAHAN, K.B.E., LL.D., F.R.S., have been elected Honorary Members. A. E. DUNSTAN, D.Sc., F.C.S., and W. R. ORMANDY, D.Sc., F.C.S., have been elected Members of Council of The Institution of Petroleum Technologists; whilst Sir ROBERT BALFOUR, Bart., has resigned his seat thereon, being no longer interested in the Petroleum Industry.

Capt. R. W. BARNETT has been re-elected M.P. for South-West St. Pancras.

Mr. E. H. Cunningham Craig left for Egypt in October.

Mr. Alexander Duckham has received from the President of the French Republic the distinction of Officer of the Order of the Legion of Honour for services rendered in connection with war supplies.

Mr. Harry S. Foster has received the honour of Knighthood.

Mr. T. R. H. Garrett is now a Major, 5th Group, R.A.F.

Mr. Wilfrid E. Guttentag has been promoted to the rank of Captain, R.A.F.

Dr. J. A. Leo Henderson left at the end of September for America, and returned to this country at the end of December.

Mr. S. Lister James returned to England in August, and left in November for the East Indies.

Lieut. I. C. Redwood, R.E., left for Russia in September.

Mr. G. B. Reynolds has returned from Venezuela.

Mr. W. Sutton has received a commission as Lieut., R.A.F.

EDITORIAL.

Technical Investigation.

It would be well if among the many schemes in preparation for readjustment of civilian life on the final restoration of peace, more attention were given to training those who contemplate, or have already commenced, a technical career. He who would be king of his life-work, in place of slavishly following the instructions of others, must be, what the word king connotes, *knowing*, for, as the old adage has it, knowledge is power. The general lines of operation may have been most accurately laid down upon a solid basis of facts, but the constantly, though slightly, varying conditions will necessitate corresponding changes in technical manipulation, possible only (in order to ensure success) to the possessor of the requisite knowledge to adjust processes to conditions.

An American author recently expressed his hope that "the bacillus of chemical engineering would produce a wholesale epidemic during the coming decade, or better still if the seed of infection could be sown broadcast, but the nutritive character of the medium should be controlled by the employment of standardized constituents." There is perhaps a little mixture of metaphor in this fervid outflow and its cautionary reservation, but we quote the whole in order to suggest a wider range of "culture," in the propaganda of the importance of training in *every* department of human thought and action.

At the same time, the training should be in the direction of free, unstereotyped conception and procedure. Whilst random speculation is likely to be futile in result (except waste of time and energy), judicious experiment, with tentative substitutions or other modifications of matter and conditions, will probably evolve effects of unanticipated advantage.

Every branch of technology affords instances of the discovery of marvellous improvements produced by what appeared to be trivial variations, sometimes accidental, more often the consequence of deliberate search for some source of dissatisfaction. It would be hard to find absolute perfection in any process or product, and the microbe of apathetic acquiescence in imperfection is the most deadly foe to progress. Physical slothfulness is universally decried, but its mental correlative passes unheeded, except by those who are unaffected by the disease.

We may hope that the number of the immune is increasing, but it is not sufficient that there should be merely an ungratified desire for improvement amongst those who have no leader towards that goal. Guidance is imperatively needed, but, as hinted above, with a judicious degree of liberty. It should not be a difficult task to arrange for such guidance.

One obvious method of providing this desideratum is the extension in various directions of the existing series of institutions in industrial centres, in which academic generalisations can be confronted with actual conditions, and harmonious adjustment effected in cases where they seem to be in conflict.

This is possible within the United Kingdom for nearly every industry, but in respect of the technology of raising petroleum and securing supplies of natural gas, study on the spot is not practicable at home. We can show neither gushers nor pumpers, and fishing jobs at 3,000 feet would need a hole drilled for educational purposes, and intentionally obstructed. Nor do the oil-fields of the Empire afford as wide a range as could be desired of the conditions under which petroleum is found.

For the desired purpose of education, productive fields are necessary in which new drilling is constantly in progress, and which collectively cover every variety of geological and stratigraphical conditions—alternations of rocks of varied coherence, and of impervious and waterlogged shales, with every angle of dip, and every degree of pressure in fluids encountered, besides other sources of difficulty in boring, whilst the dimensions and system of plant show similar variety in correlation with the natural character of the fields.

Whether in view of these considerations a system of travelling scholarships in petroleum technology might be practicable, as in some other cases of special study, is a point for further discussion.

Thirty-Second General Meeting.

This Meeting was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C. 2, on Tuesday, 15th October, 1918, Mr. Charles Greenway (President) occupying the Chair.

The Members of Council present were Messrs. Herbert Barringer, Andrew Campbell, Arthur W. Eastlake, and T. C. Palmer.

A letter of regret for unavoidable absence was received from Dr. F. Mollwo Perkin, and also from Sir Boverton Redwood who wrote as follows:—

"I had looked forward to attending and listening with great interest to the able and instructive paper to be read on the oilfields of Persia, but most unfortunately the ceremony of the inauguration of drilling operations in this country, at which I consider it my duty to be present, has been fixed for the same date."

The President in calling upon the authors said that little information had been given to the world on the subject of these remarkable oilfields hitherto, but now that their phenomenal extent and richness had been demonstrated, and that it was fairly certain that they would, when they had been thoroughly examined and developed, prove to be one of the largest, if not the largest, source of supply for the world's future requirements of petroleum, it was well that a little more light should be thrown on their geological character. He was therefore sure that the paper which Messrs. Busk and Mayo presented would be of the greatest interest to all of them, and particularly to the geological members of the Institution.

The following paper was then read, copiously illustrated by maps and sections and by lantern slides:—

Some Notes on the Geology of the Persian Oilfields.

By H. G. Busk, B.A., F.G.S., and H. T. Mayo, B.A., F.G.S.

It is proposed in this short paper to summarise the chief geological features of the oilfields in the Persian concession of the Anglo-Persian Oil Company and allied concerns, and draw attention in particular to those points in which their stratigraphy and structure differ from that of other fields. We are indebted to the Directors of the Company for permission to publish this paper.

We divide our subject into three parts, dealing with three separate regions:—i. The Bakhtiari Country; ii. The Ahwaz–Pusht-i-Kuh Country; iii. Qishm Island and the Persian Gulf Region.

I. The Bakhtiari Country.

1. Introductory.
2. Historical.
3. Stratigraphic Table.
4. Method of Geological Mapping.
5. The Asmari Series.
6. The Fars Series—Lower Group.
7. The Fars Series—Middle Group.
8. The Fars Series—Upper Group.
9. The Bakhtiari Series—Conditions of Deposition.
10. The Bakhtiari Series—Lower Group.
11. The Bakhtiari Series—Upper Group.
12. The Heterogeneity of the Three Series.
13. The Movements at the close of Bakhtiari Times.
14. The Structure of the Maidan-i-Naftun Oilfield and its Fore-syncline.
15. The Problem of Oil-finding in Outside Areas.
16. Summary and Conclusion.

Part I. *The Bakhtiari Country*, by H. G. Busk.

1. *Introductory.*—The Bakhtiari Country, under the jurisdiction of the hereditary Bakhtiari Khans, who lead one of the most powerful political factions in the Shahdom and one friendly to ourselves, is situated on the south-west side of Persia between the provinces of Farsistan and Luristan. It is contiguous with the plains of Mesopotamia, and merges north-west into the Pusht-i-Kuh country, and on the south-east into the Kuh Gahr country, the inhabitants of both the latter, living as they do upon the plunder of their neighbours, being extremely unfriendly to Europeans.

The physical character of the Bakhtiari Country is very rough and mountainous, the main Iranian ranges, which rise to 12,000 ft., bound it on the north-east, and mount gradually to the highlands of Ispahan, amongst which are situated the Khans' many fertile hill stations, which may be reached only after many days of difficult travel through rugged mountain passes. The petroliferous region lies amongst the foothills to these great mountains, against which the oil series crops out, and, though not comparable to them in magnificence and grandeur, these foothills rise, frequently precipice upon precipice, to over 4,000 ft. The district is barren for most of the year, and is visited in summer with intense heat; but, for the two months, March and April, which close the wet season, the

country is gay with a carpet of wild flowers, and every valley, great and small, is yellow with the ripening corn. After the harvest the majority of the natives, except the Company's employees, retire to the mountains to escape the summer.

The geological staff of the Anglo-Persian Oil Company, whose activities in the Bakhtiari Country are confined to these rugged foothills, has now surveyed nearly the whole of this petroliferous region, the geologically mapped ground amounting to some 2,500 sq. miles. The Maidan-i-Naftun Oilfield itself, from which the Company's main production is at present derived, is centrally situated with regard to this petroliferous district, and is some 17 miles from the Arabistan plains, across two foothill ranges, over which the pipe-line runs, rising respectively to 2,000 and 1,600 ft.

It is not intended to burden this paper with a number of place names; a generalised view of the geology, and the building of the oilfield region in historical sequence will be briefly described; and it is always to be remembered that it was only through detailed and extensive survey that such a history was finally proved.

2. *Historical.*—The Bakhtiari Country was first described by W. K. Loftus, who is the pioneer of Persian Geology (1849), and who first recognised the main stratigraphic divisions. In 1904 the region was traversed by Dr. G. E. Pilgrim, to whom we owe the naming of the main divisions of our stratigraphic nomenclature. Later workers visited the district on behalf of the Company, Mr. E. H. Cunningham Craig (1908) being the earliest in the field. To Mr. G. B. Reynolds and Mr. B. F. N. Macrorie (1909) we owe the first proper recognition of the great post-Miocene thrusts which traverse the country, work which was later amplified considerably by Mr. S. Lister James (1913), who made many important traverses and constructed with Mr. H. T. Mayo the first detailed large-scale map of the Maidan-i-Naftun Field.

Since the formation of a regular geological staff (1914), which now consists of Messrs. S. L. James, G. W. Halse, W. R. A. Weatherhead, J. Brown and the authors, rapid advances in our knowledge have been made, and facts have been brought to light which would appear to render both the geology and the occurrence of petroleum in many ways unique.

The present paper is the result of the joint researches of the above, together with those of Mr. B. F. N. Macrorie, who worked on the geological staff from 1914–1917.

3. *Stratigraphic Table.*—The main stratigraphic divisions of the region and their characteristics may be summarised as follows:—

Recent and Subrecent.		
C. Bakhtiari Series. (Pliocene.) 15,000 ft. and more ..	Upper Group (Torrential), 2,000 ft.	Massive conglomerates.
	Lower Group (Lacustrine), 13,000 ft.	Clays, shales, sandstone, conglomerate.
B. Fars Series. 7,200 ft. and more. (Miocene.)	Upper Group (Arenaceous), 2,700 ft.	Clays, shales, intercalated red and brown sandstones.
	Middle Group (Passage) (Petroliferous), 1,000 ft.	Clays, shales, intercalated gypsum, limestone and sandstone.
	Lower Group (Gypseous) (Petroliferous), up to 3,500 ft.	Massive gypsum, shales, clays, intercalated limestone, with main oil zones of Maidan-i-Naftun.
A. Asmari Series. 2,000 ft. and more. (Eo-Cretaceous.)		Massive nummulitic limestone.

4. *Method of Geological Mapping.*—The above groups are mapped separately, and, owing to their poorly fossiliferous character, are determined lithologically. A novel method for ready reference to horizons mapped in the Fars Series has been adopted, and has been found very successful, as follows:—

The basal bed of the Upper Fars Group has been mapped as "U^0."

The basal bed of the Middle Fars Group has been mapped as "p^0." (p standing for "Passage").

Other mapped horizons are named in hundreds of feet above or below U^0, or above or below p^0. For instance, horizon U^{10} lies 1,000 ft. above U^0, i.e. 1,000 ft. above the base of the Upper Fars, while horizon p^{-8} lies 800 ft. below p^0, i.e. 800 ft. below the base of the Middle Group, the minus sign signifying "below."

This method has been found very useful for the more regular Fars Series, and is a ready check upon incorrect mapping, but in the Bakhtiari Series the thickness of beds between time horizons varies so considerably in a short distance that the method is here inapplicable.

Indeed, the determination of the base of the Lower Bakhtiari forms an interesting study in the working of the method, which will be discussed in the sequel.

Geological workers in Persia lay great stress on the importance of indicating clearly the thickness of strata between surveyed

horizons on a geological map, since it is by the measurement of the thickness of strata involved in a fold that we are enabled to draw its true form below surface, a matter of first importance in oil geology. To these ends a large part of the one-inch mapping of the Bakhtiari Country was contoured simultaneously with the geological mapping; and American plane-table methods were used. The geologist himself can, as a rule, contour his ground more economically than a topographer who is not also a geologist, since he alone can judge where accuracy in contour-running is required, or where contours may merely be roughly sketched, or omitted.

5. *The Asmari Series.*—The Asmari Series consists in its upper part of a massive nummulitic limestone, 2,000 ft. thick, underlain by a shale group, which latter has not been examined in detail. The main limestone yields a prolific fauna, including many nummulites, echinoids of clypeus type, aporose corals and gasteropods. Oil-seepages have been found at the top of the series, but there is at present some doubt as to whether such oil is indigenous or derived from the Fars by downward migration.

6. *Fars Series—Lower Group.*—The Lower Fars Group consists largely of massive bedded gypsum, which characterises it. There are also clays, shales, and intercalated beds of detrital limestone, mainly a derivative of the Asmari Series. Fragmentary fossils are common in this limestone, but easily identifiable specimens are comparatively rare, and on account of this rarity little palæontological work has been done. It is in these detrital limestones that the main oil zones of Maidan-i-Naftun occur. The wells of Maidan-i-Naftun all flow under strong pressure, and after 10 years of phenomenal production show no signs of exhaustion. Details concerning the field and its production may be read in the Report of the Annual General Meeting of Shareholders of the Anglo-Persian Oil Company, 1917.

The natural oil-seepages of Maidan-i-Naftun are very prolific, and have been found to yield two or three barrels of crude per day. Many other seepages in the Lower Fars have been found.

The group varies in thickness from 1,000 ft. to an exposed minimum of 3,500 ft.

7. *Fars Series—Middle Group.*—The Middle Fars Group, which represents lithologically a passage group between the Upper and Lower Fars, consists of variegated shales and clays, with intercalated sandstones, limestones and gypsum bands. There is a gradual passage upward from the gypseous to the arenaceous type, and there is perfect conformity between the three groups. The group is rarely over 1,000 ft. thick.

Oil-seepages are common, but the beds have only once been tested by the drill, when a small show of white, naturally refined oil was encountered. In this locality (Naft-i-Safid or White Oil Springs) occurs a seepage yielding daily a gallon or two of water-clear oil, which will burn in a lamp. At Dareh-i-Qil (Valley of Pitch) 30 miles north-east of Maidan-i-Naftun there are some very prolific seepages of crude occurring in this group.

Plant remains have been found.

8. *Fars Series—Upper Group.*—The Upper Fars Group consists of purple and red shales and clays with intercalated massive sandstones, consisting of chert grains cemented in a calcareous matrix. Plant remains have been found in some of the sandstones, and the absence of marine fossils suggests a lacustrine origin. One or two oil-seepages, possibly derived, have been reported low down in the group, but in general the Upper Fars is considered unpetroliferous. At horizon U^{10} (i.e. 1,000 ft. above the base) occurs a marked arenaceous stage, some 300 ft. thick, which forms an easily-traced stratigraphic horizon.

9. *Bakhtiari Series—Conditions of Deposition.*—In marked contrast to the quiescent conditions under which took place the deposition of the Fars Series in a broad geosynclinal, extending out from the main Iranian continent across the Mesopotamian foredeep, was the Bakhtiari period which followed. Throughout this time, during which the colossal thickness, in some areas, of 15,000 ft. of non-marine Bakhtiari sediments were accumulated, there was constant, though gradual, earth-movement. Uplift and depression occurred along well-defined lines, raising the newly deposited Fars gradually above sea-level along a number of major anticlinal axes with northwest-southeast orientation and depressing the series to a corresponding extent in the adjacent synclines, in which the Lower Bakhtiaris were deposited. Once began, the transfer of material from anticline to adjacent syncline never ceased throughout this period, and in accordance with the principles of isostasy, possibly stimulated and controlled the gradual continuance of the earth movements, respective uplift and depression along the original axes.

We have called this state of affairs "continuous unconformity," and it is characterised in the Bakhtiaris by the overlap of each horizon by the one immediately above it, and by giving rise to lenticles of sediment, which reach their maximum development in the deepest parts of the synclines.

In course of time, the supply of sediment began to increase, and the earth warping began to diminish in intensity, with the result

that we pass upward from the generally fine-grained sediments of the Lower Group to the massive conglomerates, amounting to 2,000 ft. in thickness, of the Upper Group, which often rests unconformably across the steeply dipping structures beneath it. It is possible that this overlying mass of rigid natural concrete had some effect in diminishing the intensity of the earth warping.

10. *The Bakhtiari Series—Lower Group.*—The Lower Bakhtiaris consist of clays, shales and intercalated sandstones and conglomerates, the conglomerates entering sporadically, particularly towards the top of the group. Owing to continuous unconformity, the higher horizons frequently transgress those below them, over and above a general thinning out of all beds towards the flanks of the major synclines.

The determination of the boundary between the Upper Fars and Lower Bakhtiaris forms an interesting study in the mapping of horizons by the methods to which we have referred. It was found that horizons below U^{m} maintained the same thickness between them over any area within the limits of the map, but that above U^{m} there was definite thickening between surveyed stratigraphic horizons towards the axes of synclinals. U^{m}, then, where the transition occurs was chosen as the boundary between the Fars and Bakhtiari Series, and this change of type at U^{m} is now proved over the whole of the Bakhtiari Country surveyed. From a purely practical point of view it follows that estimates of thickness of strata which overlie the petroliferous groups are merely guesswork in an otherwise favourable anticline, in which horizons in the Fars Series (i.e. horizons below U^{m}) are not exposed.

Mention must be made of the sporadic occurrence of massive conglomerates, often amounting to 1,500 ft. in thickness, which may appear in the group at any horizon. These are deltaic in form, and are not usually traceable for many miles. Inspissated oil and oily residues have been found in a certain place, but these are nearly certainly redeposited from the Fars Series below.

11. *Bakhtiari Series—Upper Group.*—This group, which, except along synclinal troughs, often rests unconformably upon all rocks below it, consists entirely of massive, cemented conglomerates. These are composed of well-rounded limestone and chert pebbles, which may occur in all sizes up to many feet in circumference, the whole being compactly cemented by carbonate of lime in a gravelly matrix. The group is 2,000 ft. in thickness, and rarely dips at angles greater than 15°.

12. *The Heterogeneity of the three Series.*—We have now traced the history of the Bakhtiari oilfield region from Eo-Cretaceous to

the close of Pliocene times, and have seen that the major anticlinal axes have been already initiated and developed, simultaneously with the deposition of the Bakhtiari Series in the adjacent synclines. We have noted that this deposition has more than kept pace with the earth movement, with the result that all structures were finally hidden beneath a flat or gently-sloping plain of Bakhtiari conglomerate, lying unconformably upon them. Some idea of relative scale should be given. A typical syncline would be six to seven miles across with a thickness of 15,000 ft. of the Bakhtiari Series and, say, some 5,000 ft. of the Fars Series lying in its trough. These synclines were flanked by anticlines, which rose irregularly "en echelon." Initial pitch was as a rule very steep, amounting often to some 60°, and it is quite obvious that, had oil already been formed in the Lower Fars by that time, the structures would have been sufficiently intense for its concentration along such anticlinal lines, though, as it happens, we have no certain knowledge upon the actual date of the formation of the oil.

The history, which now follows, is of exceptional interest, for our work has proved that the oilfields, as developed at the present time, are the result of the subsequent post-Pliocene movement, which occurred tangentially along the crust, and whose nature, owing to the extreme heterogeneity of this crust, built up by the Asmari, Fars and Bakhtiari Series, was determined largely by topographic accidents, if we may call them so, the denuded remnants of which rise conspicuously at the present day.

To understand this, the heterogeneity of the three series must be further considered.

Massive gypsum, under what in diastrophism is commonly understood as light pressure, appears to act as a quasi-fluid. Wherever it is exposed and unprotected, for instance, it is always found considerably contorted on a small scale, and more often intensely folded and sheared. That the quasi-fluid state is soon reached under light pressures may be observed in the motion of gypsum masses in landslips, where it may be seen to behave very similarly to glacier ice. We have traced in such masses of gypsum, gradually slipping down a hillside under gravity, longitudinal and transverse crevasses, with actual "ice-falls" and "seracs" of gypsum, which may become repacked on the gentler slope below. The motion of such a landslip, which may be a quarter of a mile across, appears to be faster in the centre than at the sides, as proved by the curvature of the transverse crevasses.

To return to its behaviour under lateral pressure, where this gypsum is, or recently has been, protected by the more rigid Middle

and Upper Fars, contortion and shearing is absent, and therefore we may assume that similarly beneath the deep synclinal basins, where it is still further protected, the beds lie regularly and without contortion.

A point which must be particularly emphasized is the very great rigidity of the superincumbent Upper Bakhtiari conglomerate. This massive natural concrete is not found highly folded or contorted, except actually along the line of the great thrust faults to be hereafter described, yet these beds are the latest of the system of rocks that we are now considering, and overlie stratigraphically the highly-folded Lower Fars. The inherent pliancy of the gypsum was noted by Pilgrim. (Refer to his memoir p. noted in Bibliography.) It should be remembered, then, in what follows, that the pliant Lower Fars lies sandwiched in between the highly rigid Asmari Limestone below and the equally rigid Upper Fars and Bakhtiaris above it.

13. *The Movements at the close of Bakhtiari Times.*—The close of the Bakhtiari times saw the development of the present-day drainage system, the main feature of which is the deep canyon of the Karun River and its allied consequents, rising in the main Iranian chain. Gradual uplift soon recommenced along the old axes, and the thinner layer of Upper Bakhtiaris, which overlay unconformably the Fars Series along the buried anticlinal lines, was raised and stripped off by denudation, leaving exposed the inherently pliant Lower Fars gypsum along the crests of these anticlines. Continued pressure was relieved, not by folding of the normal type, but by the breaking and shearing of the gypsum along minor fault planes, and contemporaneously by the movement of the exposed gypsum masses forward to the south-west along major thrust-planes. In some cases topographic accident allowed for the free movement of the upper fault-blocks for distances measured in thousands of feet; in others the upper fault-blocks were held up by some relict mountain mass of Bakhtiari conglomerate, with resultant intense shearing and contortion of the gypsum, and the initiation of back-folding, leading to back-faulting and "fan-structures."

Earth movements of such a nature are not common in other parts of the world, or rather perhaps we may say are extremely rare, and in this short paper we have no space to reproduce all the Company's one-inch geological maps of the district, wherein lies their proof, but a glance at even a reduced map will enable the student to trace the main thrust anticlines, and he may note their passage laterally into "fan"—or as we in Persia call them

"Omega"—structures, owing to their likeness to the last capital letter of the Greek alphabet. In each instance of "omegation," a mountain mass or other obstruction will be found opposing the southwest-facing thrust-fault, giving rise to the back movement upon the other flank.

The hade at surface of the main thrust-faults corresponds exactly to the varying topography of the relict mountain over which the fault-blocks travelled, and occasionally the gypsum masses will be found jammed against a vertical wall of Bakhtiari conglomerate. In general, the hade at surface may approach 80°, but lessens gradually to 20° or less at depth, where the faults must of necessity eventually die out, for the massive limestones of the underlying Asmari Series is certainly not affected by them, and, when exposed, its surface, except for insignificant tear faults, is found unfaulted. A thrust-junction at surface between Asmaris and isoclinally folded Fars is not uncommon.

Of the present-day topographic evidence, mention must be made of the many fault-escarpments, which are remnants, occasionally well preserved, of the advancing thrust-walls.

Often it will be found that a thrust-block has progressed for such a distance over its "fore-syncline" as to completely cover it, and that it has made a very near approach to the opposing upper fault-block of the back-fault of the next "omegated" anticline, and in the particular case of Maidan-i-Naftun, the actual meeting of the opposing fault-walls has only been prevented by the activity of a river, which still maintains its consequent course along the axis of the fore-syncline and which swept away the fallen debris from them as the fault-walls approached. The river for a length of some miles runs in a gorge 800 ft. deep; on the one hand is the Tembi thrust-fault, which hades towards the oilfield, on the other is the back-fault of the next fold, which hades in the opposite direction.

We have already noted that the main thrust-movements occurred from northeast to southwest, but a remarkable instance has recently been brought to light in which an extensive thrust has moved from northeast with little or no back-faulting on the southwest side of the anticline.

The fault movements have continued, with a gradual relaxation of effort, down to the present day.

14. *The Structure of the Maidan-i-Naftun Oilfields and its Fore-syncline.*—The structure of the Maidan-i-Naftun Oilfield and its fore-syncline, which together are typical of the structures of the whole district, may be briefly considered. The south-western limb

of the anticline, in which the Lower Fars Group is deeply exposed, is replaced by a thrust-fault, whose maximum hade is 83°, and whose maximum displacement is 12,000 ft. The north-eastern limb in general dips gently northeast immediately behind the field, but the structure passes northwest into "omega" form, where this gentle limb begins to dip more steeply, and is finally reversed and back-faulted.

The fore-syncline, over which the middle limb of the Maidan-i-Naftun anticline is thrust, with its deposit of the Bakhtiari Series in its trough, is rectangular in outline, and its shorter limbs are frequently tear-faulted. Its south-western limb is invaded for a large part of its length by the back-fault block of the next anticline. Rectangular synclines of this type are a common feature, and are found repeated *en echelon* with the northwest-southeast trend of strike.

The Maidan-i-Naftun Field, with its present prolific production, lies well clear of the fault, and in the open and not the "omegated" part of the anticline. There is a well-marked boundary between the "isoclinal" or disturbed region, overlying the thrust-fault, and the region of less intense minor folding which characterises the field. The minor folding here is of more open type, its strike-lines being as a rule somewhat sinuous; it scarcely affects the actual production of oil from the main zone, which is struck at depths varying from 1,100 to 1,400 ft. The main zone appears to be disturbed to some extent by minor folding of its own, of which surface-evidence affords little indication, and geologists are consequently frequently embarrassed by their inability exactly to determine the depths at which the main flow will be struck.

This determination is of course of first importance, since, owing to rapid corrosion of casing, it is desirable that all overhead water be shut off, and the wells protected by cementation to the surface, before the main flow is encountered. Certain indicating strata, however, upon which some reliance may be placed, exist above the main zone.

The boundary between the isoclinal region and the favourable region of minor folding probably hades gently towards the field, and it has been found that those wells which have passed into the former at depth are comparatively poor oil-producers, while one instance exists of an actual failure. Oil when found in the isoclinal region seems to occur in sporadic isolated pockets.

15. *The problem of oil-finding in outside areas.*—The problem of deciding on these areas worthy of an outside test and of locating the first well in a decisive position is, with our present knowledge,

gained after some years of careful survey, a comparatively straightforward matter.

Stratigraphically, those areas where the reservoir detrital limestones are best developed in the Lower Fars Group, with accompanying seepages, should have preference. Structurally, in each anticline chosen we must place our wells so remote from the main-fault outcrops, regardless of the minor open structures, that there is no danger of passing into the disturbed isoclinal ground which overlies the main thrust-fault. The width of outcrop of the highly disturbed "isoclinal" region varies with the hade and displacement of the fault, and conversely this width of outcrop is in some measure a criterion of the hade of the fault at depth. Fault displacement may be measured by mapping.

Omega structures are not as a rule considered favourable for testing, since steeply dipping beds are liable to be encountered at depth, and suitable reservoir rocks are liable to be pinched out.

Pioneers in Persia are much to be congratulated in their enterprise, in a region fraught with many political and transport difficulties, in their following up the first test well at Maidan-i-Naftun with other wells, which have now proved an area which, on account of its richness and phenomenal productivity, entitles it to be classed amongst the great oilfields of the world.

16. *Summary and Conclusion.*—We may summarise the salient points introduced in this paper as follows:—

(1) The petroliferous group in the Bakhtiari Country is of Lower Fars (Lower Miocene) Age, and consists in the main of massive bedded gypsum, with intercalated detrital limestone, which latter is the reservoir rock.

(2) The deposition of the Fars Series, which contains the oil group, is conformable and is undisturbed by contemporaneous earth movements.

(3) On the other hand, the deposition of the Bakhtiari Series, which overlies the Fars, was accompanied by contemporaneous earth movements, along well-marked axes of folding, oriented northwest-southeast, which have given rise to the phenomenon of "continuous unconformity."

(4) The gypseous oil group, which becomes quasi-fluid under pressure, is sandwiched between two rock-series of great comparative rigidity. Where left unprotected by the overlying rigid Upper Fars and Bakhtiaris, this gypseous group responded to a renewal of pressure by becoming faulted along extensive thrust-planes. These major thrusts are accompanied by intricate structure.

(5) The oil is sought for in the petroliferous group well remote from the major thrust-faults, and centres the position of the Maidan-i-Naftun Field.

In this brief résumé of the Bakhtiari Country we have followed the story of the structure-building of the oilfield region, but we have not attempted to give proofs for the novel features which have been introduced. Such proofs exist in the Anglo-Persian Oil Company's geological maps, which may, perhaps, when time is ripe, be published. The evolution of these maps, and the crystallisation of our ideas, as the facts were step by step disclosed, have been for the Company's geological staff, apart from the knowledge of its economic value, an entrancing study. But as yet merely the outlines of the geology have been proved, and many questions still await solution. It is certain that the excellence of the exposures, in a country bare of vegetation, the close conformation of the topography to structure, and the unique problems in tectonics which are there unfolded, together with the extraordinarily rich stores of petroleum which have now been proved to exist, will undoubtedly focus the interest of geologists upon the Bakhtiari Country for some time to come.

Part II. The Ahwaz–Pusht-i-Kuh Country.

1. *Introductory.*—The geology and oil prospects of the Ahwaz area were first investigated in 1913, when a portion of the ground E. of the Karun River in the neighbourhood of Ahwaz was surveyed and a test-well located. The only previous work in the neighbourhood had been the regional surveys of Loftus and Pilgrim, who had, in 1855 and 1908, noted the Ahwaz outcrops, and included the hill range which they constitute in their geological sketch-maps. Loftus included the whole of the Fars and Bakhtiari Series in his "gypsiferous" group, whilst Pilgrim mapped the range as exclusively Bakhtiari Series.

2. *Physical Features.*—The Ahwaz range, a low and irregular anticlinal line of hills striking W.N.W. and E.S.E. through Ahwaz, is the farthest recognisable outlying fold of the Iranian mountain chain. Forty miles of desert intervene between it and the Tulkhayat-White Oil Springs fold to the N.E.; on the S.W. the great Mesopotamian alluvial plain stretches away into the interior of Arabia.

The fold has been traced for a distance of over 100 miles, N.W. and S.E. of Ahwaz; throughout its extent it presents an extremely barren aspect, entirely destitute of vegetation and devoid of water-supply. The highest points, which are Upper Fars sandstone

scarps, do not attain a greater height than 400 ft. above the level of the plain. Denudation of the range has reached a very late stage.

3. *Stratigraphy.*—Owing to the isolated position of the range and the discontinuous nature of exposures, difficulty was experienced for some years in establishing anything like an accurate stratigraphic correlation of the Ahwaz rocks with Maidan-i-Naftun. At the time of Ahwaz no. 1 test-well, an approximate correlation with White Oil Springs and Maidan-i-Naftun was adopted, based on general lithological characters, particularly the occurrence of conspicuous chert grits at a high horizon (Bakhtiari Series) in each area. The lowermost two or three hundred feet of beds exposed were classed provisionally as a sub-group of the Upper Fars. Later they were recognised as belonging to the Middle Fars Passage Group, a correlation which was confirmed by the survey of the more remote north-westerly extension of the fold.

Though exposures are not continuous northwestwards from the Ahwaz neighbourhood, intermittent portions of the fold show well-defined gentle undulations of the anticlinal axis, and render possible a correlation of outcrops. Characteristic limestone bands in the Middle Fars Group, when this is exposed, are immediately recognisable, and can be traced by their debris for miles across the desert.

The Lower Fars, several hundred feet of which are exposed at Jebel Mishdakh, 40 miles W.N.W. of Ahwaz, is of normal Bakhtiari Country type. The Middle Group is a somewhat arenaceous facies, but includes the limestone bands referred to, and bedded gypsum towards the base. The Upper Fars consists of a normal succession of reddish brown sandstones and shales or clays. The Bakhtiari Series with its great thickness of pale brown clays, sandstones and chert grits follows conformably on the flanks of the Ahwaz fold, though farther to the N.W., in the Dalpari area, continuous overlap, just as in the Bakhtiari Country, is responsible for local unconformities. Following the system of notation so successfully employed by Messrs. Busk and Weatherhead, the Bakhtiari Series is reckoned as commencing from about the horizon U^{28} or U^{24}. The Upper Fars sandstones and Bakhtiari grits prove a recession of the Miocene Fars sea, and transition from marine to beach, and beach to fluviatile conditions.

The stratigraphic table given in Part I shows the divisions of the Fars and Bakhtiari Series. A word may be said here concerning the position of the Asmari Series. The Asmari limestone is the "Nummulitic" limestone of S.W. Persia and the Gulf region

as mapped by Loftus and Pilgrim, and is referred by the latter to the Middle Lutetian division of the Eocene, but from fossil collections, both in the Bakhtiari Country and at Dalpari, a Middle or Upper Oligocene Age seems to be indicated, which would accord with the observed general absence of a physical break between Asmaris and Lower Fars. Only a few of the fossils in question, however, have been identified, so this correlation is only adopted tentatively.

4. *Structure and Geographical.*—The nature of the earth-movements which elevated the Iranian mountain chain in Pliocene and Pleistocene time have been described in the first part of this paper. The structure of the furthest outlying fold is that of an asymmetrical anticline, with steep, vertical or inverted S.W. and gentle N.E. limbs. Faulting or overthrusting is not developed when the gypsum group occurs braced by a sufficient overburden of Upper Fars sandstones, etc. This, as already explained, is a structural condition which obtains generally; it is well illustrated at Jebel Mishdakh, where faulting of the gypsum has occurred along the axial plane, but dies out rapidly to the N.W. as the gypsum group pitches below superincumbent Middle and Upper Fars beds.

In the neighbourhood of Ahwaz, the undulations of the anticlinal crest, whose course at the surface is slightly sinuous, but follows a general line of strike W.20 N. and E.20 S. result in the formation of a series of elongated domes. It was on the north-easterly flank of one of these, the most prominent in the immediate neighbourhood of Ahwaz, that the first Ahwaz test-well was drilled. Another, exposing a slightly lower horizon at its apex, occurs about seven miles W.N.W. of Ahwaz. In the region of the Karkheh River another fold makes its appearance, running parallel to the Ahwaz fold and about five miles to the north-east.

On this axis, near Sinn el Abbas, 20 miles N.W. of Ahwaz, the most extensive and striking dome structure in the area is developed. There is a considerable degree of asymmetry, the S.W. flank being steep but not inverted. The crest, near the apex, where the uppermost beds of the Middle Fars Group are exposed, is marked by brine springs. Jebel Mishdakh, 20 miles W.N.W. of Sinn el Abbas, is on the same axis. Outcrops over most of the intervening portion of the fold are obscured by blown sand, which also renders the ground very difficult of access. Both the Ahwaz and Mishdakh folds are traced north-westwards into the Dowairij and Tyb Rivers district, but here the continued north-westerly pitch has buried the Fars strata deeply beneath overlying Bakhtiari grits and sandstones, a high horizon in which persists along the axes

of the folds. Upper Bakhtiari sandstones, pebble beds and pale brown clays constitute the whole of the gently undulating barren plain which stretches away to the N. and N.E. of the Mishdakh range and the Dowairij-Tyb district.

At the foot of the Pusht-i-Kuh range, however, in the Deh Luran-Dalpari district, the whole Fars succession outcrops again, against the flank of a great Asmari limestone dome. As is invariably the case in such conditions, the gypsum group is isoclinally folded and disturbed to such an extent that accurate measurement of its thickness is impossible. The facies is that of Jebel Mishdakh, but below the gypsum beds is a conformable group of thin cream-coloured limestones or marls and dark blue clays, more than 1,000 ft. thick, which conformably overlie the massive Asmari limestone. Both gypsum and limestone groups are petroliferous.

Method in section drawing for the fixing of locations on the flanks of asymmetrical anticlines of Ahwaz type, is a problem in Persian oil geology which has naturally demanded a good deal of attention —the more so since it was found that the first Ahwaz test-well, which was located on the gentle flank of a sharply asymmetrical dome, had gone over the subterranean crest at comparatively shallow depth. Sir Thomas Holland's paper on geometrical features of the anticline, read at the inaugural meeting of this Institution, summarises the structural features of asymmetrical anticlines, and outlines a simple geometrical method based on the formula given by Mr. E. H. Pascoe in the Records of the Geol. Surv. of India, vol. xxxiv, pt. 4, for section construction in ideal cases. An earlier geometrical method, which however did not provide for the case of folds having an inverted limb, was used by Mr. H. J. Davies, formerly of the Burmah Oil Company's Geological Staff. Messrs. G. W. Lepper and H. G. Busk have recently introduced a method of arc construction which provides a natural curve for *correlated* beds on the opposite flanks of a fold, and for the interpolation of horizons between mapped beds, but this method is also only applicable to anticlines with a steep limb not exceeding verticality.

The difficulties which have to be contended against are principally: (1) Paucity of exposures, rendering impossible the correlated mapping of a sufficient number of individual beds on opposite flanks of the fold. (2) Compression of the steep limb; the degree of compression can of course only be proved at surface, and that only by accurate mapping of correlated beds. (3) Change of the fold-form at depth; as Mr. Cunningham Craig points out in "Oil Finding," p. 137, "when we consider that the flexure has been caused by tangential stress, it is obvious that the hade of any

asymmetrical flexure must decrease downwards, and finally disappear altogether."

Thus, in the reconstruction of the fold-form at depth, geometrical methods may involve unwarrantable assumptions, or give only results varying within wide limits.

5. *The Petroliferous Group.*—Most of the notable oil-seepages of S.W. Persia occur in the Lower and Middle groups of the Fars Series. Instances also occur of seepages in the uppermost beds of the Asmari Series, usually at or near the pitching ends of elongated Asmari domes, where the latter are enveloped by the Lower Fars gypsum, but these are generally agreed to be due to migration of oil from Lower Fars reservoirs. Similar derived seepages are also recorded from Upper Fars and Bakhtiari strata in certain instances where the petroliferous gypsum group is faulted against them. It should be mentioned that the Euphrates limestone, which is regarded as the stratigraphic equivalent of the Asmari limestone, is claimed by Mr. Halse to be the original source of extensive oil and bitumen seepages in Mesopotamia.

However, there can be very little question that the vast stores of oil in the Maidan-i-Naftun field originated in the Lower Fars group. To what extent the oil was generated actually *in situ* or whether from an animal or vegetable source is for the purposes of this note immaterial; the fact remains that it is stored almost exclusively in the vesicular limestones of the Gypsum group, and it is in such beds, if at all, that we must rely on finding it in the Ahwaz anticlines.

6. *Oil Prospects.*—The factors upon which the success of a test-well in the Ahwaz area depends then, are:

(1) Geological structure. It has already been shown that several portions of the Ahwaz and Mishdakh range folds are characterised by structure highly favourable for the storage of petroleum.

(2) Stratigraphic position relatively to known oil horizons. The initial horizon for test-wells on such portions of these folds is in several cases sufficiently low to allow of the main producing oil zone of Maidan-i-Naftun being reached at moderate depth.

(3) Presence of suitable reservoir rocks at such horizons. There is good reason to believe that the Lower Fars gypseous group, with suitable reservoir rocks, is normally developed beneath the Ahwaz area. (*a*) In the Dalpari-Deh Luran district the group is well developed, and includes near its base, at approximately the horizon of the upper limit of the Maidan-i-Naftun main oil zone, about 200 ft. of fairly massive limestone, which yield a number of conspicuous bitumen and oil-seepages. Below is the group of

alternating limestones and clays previously referred to, also richly petroliferous. (*b*) Several hundred feet of the Gypsum group are exposed at Jebel Mishdakh, and some part of the Passage group, at intervals, throughout the area; the thickness of the latter when fully exposed is constant, and the facies remains unvaried.

(4) Existence of oil in sufficient quantities for storage in such reservoir rocks. This is of course the uncertain factor. We know that the district lies within the general limits of the oil belt, and that to the N.W., at approximately the petroliferous horizons of Maidan-i-Naftun, limestone, gypsum and marls occur, richly impregnated with oil; but in the neighbourhood of Ahwaz there are unfortunately no oil-seepages, so there must inevitably be an element of speculation in drilling. However, the geological conditions, and facilities for access and transport, are such that a final test will no doubt eventually be drilled.

PART III. QISHM ISLAND AND THE PERSIAN GULF REGION.

1. *Qishm Island.*—Interest in the geology of Qishm Island from the point of view of oil-winning dates from the Admiralty Commission of 1913–14 which visited and reported on various areas in the Persian Gulf region. At that time the island had only previously been geologically examined by Dr. Pilgrim, whose account of it is given in his Memoir on the Persian Gulf, *Mem. Geol. Surv. India*, vol. xxxiv. It was surveyed later in the same season by Messrs. James and Dewhurst, of the Burmah Oil Co.'s Geological Staff.

Qishm is the largest island in the Persian Gulf, and is situated near its entrance, opposite the coast between Lingah and Bunder Abbas. It is more than 60 miles long, and has an average breadth of from 8 to 10 miles.

2. *Stratigraphy and General Structure.*—Apart from raised beaches, consisting of sub-recent shelly limestone or calcareous grit, the only rocks exposed are those of the Hormuz Series, the Upper group of the Fars Series, and the Pliocene Tersai Series.

The Upper Fars beds, clays, marls, sandstones and shelly limestones, occupy by far the greater part of the island. They belong to Dr. Pilgrim's Pecten Vasseli Stage, and were divided by Messrs. James and Dewhurst into Upper Arenaceous and Lower Argillaceous groups, and later by Mr. Busk into two sub-stages characterised by species of Pecten.

Structurally, they are disposed in a series of gentle domes along an E.N.E. and W.S.W. axis running through the length of the island.

The Hormuz Series, as on the mainland and the other islands—in fact, in its every known occurrence—constitutes a roughly

circular inlier, with the uppermost beds at the periphery steeply or vertically disposed. The " Namakdan " inlier is situated at the S.W. end of Qishm, on the general axial line of the Upper Fars domes and between the two most westerly of these.

3. *The Hormuz Series and Stratigraphy of the Salakh-Namakdan Area.*—Concerning the age and nature of this series there has been much controversy. Two distinct rock groups are included, separated by an unconformity. These are a basal Namakdan group with massive rock-salt, laminated shales, and dolomitic limestone, and an upper pyroclastic Pusht-Tumba group of volcanic agglomerates, and gypseous tuffs, etc. These two groups are found associated, in this order, in numerous other islands in the Persian Gulf (e.g., Hormuz, Henjam, Larak), and on the mainland, as at Champeh and Khamir. Dr. Pilgrim included them together in a single series (as had Blanford, earlier, in a cursory examination of the Gulf region), and assigned to it a post-Cretaceous pre-Nummulitic age.

The controversy hinges upon the stratigraphic and structural relations of the Pusht-Tumba and Upper Fars beds at the margin of the inlier. Dr. Pilgrim, though he does not in his Memoir specifically state that the junction is unconformable, obviously intends this to be understood. Messrs. James and Dewhurst, in their original report, described contact metamorphism of the upturned Upper Fars beds at the Hormuz junction, which they attributed to *igneous intrusion* by the Hormuz Series. They did not, however, consider there was reason for believing the intrusive Hormuz Series would be met with at shallow depth in the five Upper Fars domes which they mapped in detail, and a test-well was recommended, and after various delays started upon the Salakh dome, which exposes at its apex the lowest horizon in the Upper Fars beds on the island, and possesses besides a good oil-seepage.

In May, 1915, a portion of the critical Salakh-Namakdan area was surveyed in detail by Mr. Busk, who first recognised the unconformity between his Namakdan and Pusht-Tumba groups, but the examination of the whole Hormuz inlier and of the adjoining mainland was unfortunately prevented by political disturbances, due to the war, which interrupted all operations on the island for a considerable time. Mr. Busk showed that the Hormuz–Upper Fars junction is not an intrusive one. From the evidence available in the Namakdan area he concluded that the Pusht-Tumba beds pass *conformably* upward into the basal Upper Fars shelly limestone. Hence, he argued that the Pusht-Tumbas were a volcanic facies of the Middle and Lower Fars groups, a correlation which,

of course, had a very important bearing on the prospects of the Salakh well, which was designed to test a normal gypseous facies of the Lower Fars presumed to underlie the Upper Fars in the Salakh dome.

Later work on Qishm, however, and particularly on the adjoining mainland in the vicinity of Khamir, proved that the Pusht-Tumba group is quite distinct from any members of the Fars Series, being not only of pre-Fars but of pre-Oligocene age. The record of the well, too, has proved that after passing through the Upper Fars beds, it entered first the normal Middle and then the normal gypseous Lower Fars groups as developed on the mainland. The well is now, at a little over 2,000 ft., in the latter formation, and has recently encountered several light shows of gas and oil.

Qishm Island has thus provided a striking example of the principle, so often vindicated in oil geology, that for the solution of the stratigraphy of an area where it is proposed to test a series not exposed in the immediate neighbourhood, all available relative evidence from outlying districts, no matter how far distant or apparently detached, should be examined, and its bearing on the problem carefully gauged. In this way it has been shown that the key to the stratigraphy of the Salakh-Namakdan area is progressive overlap, the Middle Fars group overlapping the Lower, and the Upper the Middle, against the older Hormuz Series.

4. *Origin of the Qishm Domes, and the Hormuz Inlier.*—Controversy concerning the geology of Qishm has not been confined to problems of stratigraphy; the origin of the domes, and of the Hormuz inlier, has been the subject of a good deal of discussion and dispute. The following theories have been advanced:—

(1) That the domes have been produced by two sets of earth-movements, of slight intensity, operating at right angles to one another (S.S.E.–N.N.W. and S.W.–N.E.). This view is enunciated by Mr. Dewhurst in his Review of the Geology of Qishm Island of 1917. "The central point of the Hormuz mass," he remarks, "must lie on or close to the continuation of the axis of the fold" (i.e. the main fold of the island, induced by the south-southeasterly earth-movement), "thus suggesting that the position of the Hormuz mass was determined by the previous existence of the fold."

(2) The "Salt-dome" theory outlined by Sir Thomas Holland in a Note of July 28th, 1915. The argument is that the Hormuz inliers of the Persian Gulf and the domes of Qishm are respectively breached and unbreached examples of "salt-plug" action, of a type similar to that exhibited by certain domes in Transylvania which are believed to owe their origin to the self-extrusion of underlying

salt masses. Salt-cored domes also occur in Egypt, and at Spindle-Top in Texas, though it should be mentioned in the case of the former that Dr. Hume, Director of the Egyptian Geological Survey, considers the salt aggregates to have accumulated in the domes as a *consequence* of the initiation of dome structure, and not to be primary causes of doming.

(3) The Laccolitic Igneous Intrusion and "Cauldron Subsidence" theory. At an early stage in the geological investigation of Qishm Island, Mr. Cunningham Craig suggested that the gentle domes might be due to underlying laccolitic igneous intrusions. Later, when Messrs. James and Halse issued their report on the geology of the country between Lingah and Bunder Abbas, with its accompanying map showing the mode of occurrence and disposition of the several Hormuz inliers of the region, he maintained that the mapped evidence "points very clearly to a movement of elevation from below rather than tangential pressure," and elaborated his view thus: "The domes have been formed as volcanic vents, probably over intrusive masses of igneous rock of the nature of laccolites. Probably the quantity of ejectamenta was not great, but a long continued solfataric stage succeeded, or alternated with, more active vulcanicity. The formation of the dome must have been the first stage, the active vulcanicity probably the second, and the solfataric the third, but the latter stage was accompanied by a 'Cauldron subsidence' which may have taken place in stages also. The dome may have been accentuated by the accumulation of ejecta to some slight extent."

(4) Finally, there is the somewhat unorthodox theory of Messrs. James and Halse: "With regard to the formation of these domes whether with Hormuz inlier exposed or not—their incipience may perhaps be accounted for by the consolidation and compression of the newly deposited Fars strata about eminences or bosses of older rock." (Report on Lingah-Bunder Abbas.)

5. *The Persian Mainland in the Gulf Coast Region. General Stratigraphy and Structural Features.*—It is obviously impossible to enter here into detailed descriptions of the geology of this vast region; it will be sufficient to indicate the general stratigraphic and structural features.

The first attempt at a co-ordinated account of the stratigraphy of these parts was made by Dr. Blanford, in the course of a voyage up the Persian Gulf in 1872. Blanford noted a continuous coastal series of pale grey clays, of great thickness, with occasional thin beds of darker shelly limestone or calcareous sandstone, from Cape Monze to Bushire (a distance of about 1,200 miles). For these beds

he proposed the name "Mekran" Series. The fauna was found to be quite distinct from that of the underlying Nummulitic Series, being characterised by abundant Balanus, Pectens and Ostreas, and containing several species identified with living forms. He recognised several inliers of the Hormuz Series, which he described as "much older than the Mekran Series." His classification of the Gulf Coast rock-groups was:—

Sub-recent Shelly limestone or calcareous grit (the raised beaches of Jaskh, Qishm, Bushire, etc.).
"Mekran" Series.
Nummulitic Series.
Hormuz Series.

The "Mekran" Series includes the Miocene Gaj and Pliocene Hinglaj of the Mekran Coast, and the Miocene Fars and Pliocene Tersais of the Persian Gulf.

The continuity of the "Gypsiferous" Series (which included the Fars and Bakhtiaris) throughout S.W. Persia was proved by Loftus, 1849–52, and that of the Fars and Bakhtiari Series from the Bakhtiari Country S.E. along the coast to Gwadur on the Mekran, by Pilgrim, 1904–5. An independent survey by another Company of part of Las Bela and the Mekran Coast was carried to the Persian frontier a lithological classification of the strata being adopted, thus:—

Hinglaj sandstones.
Passage beds.
Clay group

—so it will be seen a general stratigraphic correlation has been effected from the Indian frontier into central S.W. Persia.

It may be mentioned here that the initial horizon of a test-well, which is being sunk on the Chandragup dome, 100 miles W. of Karachi, is the Passage group of the above table, so the strata which it is designed to test are approximately the stratigraphic equivalent of the petroliferous Lower Fars group of Persia. They are also approximately to be correlated with the petroliferous Pegu Series of Burma and with the oil rocks of Assam.

A great deal more palæontological work is required and will have to be done in Persia, but at the same time, in dealing with the stratigraphy of so vast an area, we have to remember that palæontological correlations, such as those so successfully worked out for Baluchistan and Western India by Vredenburg, and for the Persian Gulf region by Dr. Pilgrim, cannot be rigidly applied throughout indefinite stretches of country. For instance, as Mr. Cunningham Craig points out, "the Oligocene Nummulitic

Limestone and Khamir Clay (of the Lingah-Bunder Abbas District) may be the equivalent of the Lower Fars of the Maidan-i-Naftun area, where of course conditions for the formation of a Nummulitic limestone were wanting."

The main tectonic feature of the Persian-Mekran region is the E. and W. running folds, parallel with the coast; the folding movement began in late Pliocene times and has continued down to the present day. The existence of an important land-barrier between the Persian and Mekran areas has been proved by Messrs. James and Halse's mapping of the ground E. and N. of Bunder Abbas; this is comprised in the fault-bounded Zindon Range which runs in a north-westerly direction inland from the coast a few miles E. of Minab.

6. *Lateral Variation of the Fars Groups.*—Lateral variation along the general line of strike has been traced in the Fars groups between the Bakhtiari Country and the neighbourhood of Bushire. South-east of Khalafabad, the Middle and Upper groups become markedly more argillaceous. The gypseous group also assumes a deeper water facies, the proportion of gypsum becoming greater and that of intercalated sediment less; limestones are not so strongly developed, and the whole group is much reduced in thickness. In the neighbourhood of Ahram there is very little gypsum.

From Bushire to Lingah stretch about 300 miles of practically unknown country. The general continuity of the Fars Series has been observed, from the sea, but there has apparently been no closer geological examination of the rocks.

In the Lingah-Bunder Abbas area the same reduced development of Lower Fars is found. There are two phases of the Upper group: the Salakh phase with shelly limestones, and the easterly arenaceous Minab phase of normal type.

7. *Oil-seepages and Conditions of Occurrence.*—Slight seepages or traces of oil are recorded at a number of localities, and from several geological horizons in the Lingah-Bunder Abbas region, e.g. from the Eocene and Oligocene Nummulitic Series, and even from the Carboniferous Oman Series.

Other than that of Salakh, only one small seepage is known from rocks of the Fars Series.

Seepages in the Lower group are not known nearer than Daliki, N.E. of Bushire.

The conditions of deposition of the coastal Fars facies do not appear to have been so favourable for the accumulation of oil in large quantities as were those obtaining in the Bakhtiari Country.

Concerning the origin of the widespread and regularly thick-

bedded gypsum of the Lower Fars group, it should perhaps be noted that neither Loftus nor Pilgrim accept in respect to it the explanation usually advanced for the accumulation of such deposits, namely, desiccation and precipitation in land-locked or partially land-locked basins (e.g. our own Triassic gypsum). These observers both hold that the Lower Fars gypsum deposits are too extensive to be accounted for in this way, and suggest the emanation of sulphuric vapours, in an area "which up to recent times we know to have been one of vulcanicity" (Pilgrim, p. 33), with consequent reaction on calcium carbonate in solution.

From the foregoing notes it will be readily understood that a very great amount of geological work remains to be done in Persia, and on the Gulf and Persian-Mekran coasts. Only small portions of the Anglo-Persian Oil Company's vast concession have so far been surveyed.

DISCUSSION.

The President said he had no remarks to make himself upon this extremely interesting subject, but perhaps those members who knew more about the scientific part of it than he did, would be able to give their views on the deductions of the authors of the paper, which might throw further light on the subject.

Mr. A. W. Eastlake remarked that he was sure they would all be glad to see their President occupying the Chair again after his serious illness. He did not propose to discuss the most excellent and instructive papers which had been read, except to say that in his opinion the Institution was to be congratulated that Messrs. Busk and Mayo were induced to give them, and certainly had to thank the authors for showing some splendid geological illustrations.

Mr. S. Lister James congratulated the authors on the very able way in which they had treated a region of exceptional geological interest. The paper was of special interest to him on account of past fieldwork in the Gulf and of his continued, though distant, connection with that region. He had no desire to take up much time, but there were a few matters to which he would like to refer. The novel method adopted in referring to horizons was one which might be widely used with great advantage. Mr. Busk referred to the main oil zone apparently being disturbed to some extent by minor folding of its own. An alternative, and to his mind, more plausible solution for the irregularities to be accounted for, was in the very lenticular habit of the limestone oil rocks as clearly observable at the surface. He suggested that

any underground puckering must necessarily be confined to the immediate vicinity of the faults. The nature of the oil rocks and the origin of the oil were subjects of considerable interest on which more might be said. The following notes were taken from a report made some years ago embodying further results of a detailed geological survey of the Maidan-i-Naftun field :—

In the lowest group of the Lower Fars exposed occur thick beds of limestone saturated with oil forming the chief source of surface seepages. These beds, where fully developed, are composed mainly or entirely of pumice-like or vesicular limestone in which large crystalline aggregates sometimes appear. What may best be described as "flow structure" is often discernible where the beds assume this nature. They vary rapidly in character and thickness. It is a most significant fact that individual thick beds of pumice-like limestone, when traced, are found almost invariably to alter to thin shelly bands, which are, moreover, distinctly bituminous in observed instances. This change has been observed to take place over a distance of only about 20 yards.

Apparently the only explanation of the origin of these beds, which will agree with all observed evidence, was as follows :—the limestones are essentially of organic origin rather than detrital and they represent banks of mollusca accumulated rapidly, probably by tidal action. It might be remarked in support of this that examples of current bedding and ripple marking have been observed slightly higher in the series. The live mollusca accumulated in this way must perish almost entirely. With continuing deposition these banks of organic matter would be covered and sealed. Where the deposit was thick and rich, a viscous mass would be formed in which the shells would be disintegrated, and the calcite recrystallised, the nascent oil separating into globules occupying the interstices: hence the ultimate production of a vesicular limestone saturated with oil.

Another very important feature of these somewhat peculiar limestones was their great lenticularity. Observations made on them had been applied confidently to the oil-rocks from which the actual production was obtained, for the drilling records showed a continuation of similar conditions through the intermediate strata. This character of lenticularity would probably be proved to modify very considerably the effect of structure, *i.e.* in restraining and localising the migration of the oil. The lower limestones had been described as detrital, but he would be interested to know whether their detrital character had been demonstrated at a distance from any Asmari inlier.

Mr. Mayo had referred to the observed general absence of an observed physical break between the Asmari limestone and the Lower Fars. At Daliki, however, it should be recorded that unconformability and overlap were observable between the two series, the overlap accounting for the thinning out of the Lower Fars in this vicinity.

With reference to Qishm Island he was recorded as having described contact-metamorphism of the Upper Fars beds at the junction with the Hormuz series. After a subsequent visit it was found absolutely necessary to abandon the idea of contact-metamorphism. His colleague in the work not having had the advantage of a second visit still, he believed, retained his original view. There had been a great deal of controversy over Qishm Island in the past, but he believed everybody was now in agreement on matters of practical importance.

Mr. V. C. Illing stated that he had no personal knowledge of the Persian beds, though he had a slight acquaintance with their probable equivalents in the Punjab and Mediterranean region. What he wanted to say on the paper was from a purely geological rather than from an oil-producing standpoint. The paper presented a complex of geological problems. He congratulated the authors on the non-stereotyped way in which they had dealt with the whole subject. Folds were too frequently spoken of as if they were simple structures in which every bed followed in conformity the curves of the one below. In Persia the successive formations consisted of beds of very different nature, the extremes of hardness and softness, and the authors had laid stress on the different way in which these reacted to the earth-stresses. The harder tended to buckle and thrust, while the softer folded and flowed. As a matter of fact, this phenomenon was by no means unique; the case of the Persian structures was merely a fine example of the general rule, that lithology is of primary importance in determining the way in which a formation yields to lateral pressure. The ability of some strata to resist the disruptive effects of earth-stresses, and to yield in broad open folds, was specially recognised in the term "competency."

The way in which the authors differentiated their horizons by a thickness-nomenclature was interesting, and could be adapted usefully to much further work. Of course, no warning was necessary to the geologist of its inevitable limitations and dangers in cases of erosional features, both overlap and overstep, and where the strata were deposited in deepening water producing a gradual diminution in thickness. There was one point on which the

speaker desired further information, the extent of the disconformity at the base of the Bakhtiari series. When discussing the formation of the latter, the authors represented the conditions in the country as of isostatic equilibrium, with exposed anticlines, and areas of deposition in the synclines. Did they infer that a large amount of the Bakhtiari sediment had been produced by erosion of the underlying Fars series exposed in the anticlines? Had it not rather come mainly from regions farther north, the uplifted area of the main mountain system?

This led the speaker to another interesting point, the age of these movements. He understood the authors to state that they were probably late Pliocene. Such a correlation was difficult to reconcile with the age of movements in neighbouring regions, which were generally considered to be mainly of Miocene age. The speaker would suggest that the folds and thrusts of the foothills on which the authors had rightly laid such stress, were rather, and especially in their intense phase, produced as a later secondary feature, by the erosion of the competent formations and the consequent redistribution of the superficial crustal blocks under pressure from the mountains to the north. It was an important point, whether it was legitimate to allocate the age of the main mountain-building movement from the evidence of the foothills. He was personally inclined to believe that the thrusting which the authors described was merely a later phase of readjustment following the main folding movements of the North-Persian mountain-system, which were of much earlier date.

Mr. Busk, in reply to the discussion, thanked members of the Institution present on behalf of himself and his colleague for the kind reception that had been accorded to their paper.

With regard to Mr. James's suggestion concerning the lenticularity of the main oil zone, it was hardly likely that lenticularity alone could account for discrepancies in geological depth-production, which often amounted to 200–300 ft.

As to the question of the origin of the oil, there was very little evidence either way so far. There appeared, however, to be some chemical evidence in favour of the animal-origin theory. He believed that Dr. Dunstan had discovered that analysis of the water from horizons overlying the main oil zone gave a result very similar to that which is obtained from present-day sewage water.

In reference to the origin of the limestone reservoir-rocks, the lateral change from shelly to cavernous limestone illustrated by the specimens exhibited by Mr. James, was undoubtedly a very

striking one, but it was to be remembered that similar changes from shelly rock to a limestone whose origin was undoubtedly detrital, consisting as it did of eroded grains of limestone cemented in a calcareous matrix, was equally striking, and that such a facies of detrital limestone was the usual one for the district, the shelly type being merely local and not very persistent. The Fars limestone might be traced north-eastwards to its origin in the Asmari mountains, and pebbles of Asmari limestone were not uncommon in the Fars limestones. The fact that the oil is found in such detrital limestone is indecisive one way or the other as regarding the origin of the oil, bearing in mind its highly migratory character.

Upon the question of roads, the exploration-work of the Geological Survey lay outside the regions at present developed by the Company, where there were only very rough nature-made mule-tracks. There was a road through the hill section approaching the oilfield about 30 miles long, but on the Mesopotamian plains no road-making was necessary.

In answer to Mr. Illing's remarks, it had been their special care that the system of indexing horizons according to thickness should not mislead them. Obviously the scheme was inapplicable to a variable series such as the Bakhtiaris were. The source of origin of the Bakhtiari sediments, lying lenticularly in the synclines, was undoubtedly the flanking Bakhtiari ranges. Each synclinal basin appeared to have its own special facies, until late Upper Bakhtiari times, when the conglomerates finally transgressed over and buried the intermediate anticlinal ranges.

The correlation of the thrust-movements with diastrophic action of other areas was difficult to determine owing to the paucity of fossil evidence. Fossils from the Asmari series, which were then undergoing detailed examination, seemed to prove the Eo-Cretaceous age of these rocks, making the Fars series Miocene, and the Bakhtiari Pliocene. He agreed with Mr. Illing's suggestion that the later thrusts might be due entirely to "topographic effect"; that the earth-stresses, though not evident owing to the rigidity of the covering of conglomerate, were continued up to and after Upper Bakhtiari times, and that the thrust-movements commenced as soon as this rigid covering was removed by denudation. The semi-fluid nature of the Lower Fars gypsum under pressure was constantly to be borne in mind. Much smaller stresses might be sufficient to cause thrusting in the gypsum than were required for the original warping of the Bakhtiari synclines.

The President thanked the Hon. Secretary for the kind remarks he had made regarding his health, and for the reception given him

by the meeting. It was a great pleasure to him to be once more occupying the Chair.

With regard to the conditions under which the geologists had to live in Persia, the question of adequate compensation was purely a matter for the Company to deal with, and there was no reason for supposing that the Company would treat its employees less liberally than any other company. He thought they might have got rather a wrong impression from the photographs they had seen on the screen. The hills and mountains of Persia might appear bare and ugly, but they possessed charms which no one who had not been there quite realised. From the climatic point of view he thought the geologists engaged in Persia were far better off than those whose work carried them into jungle country, such as Trinidad and many others, from which ultimately the bulk of the world's supplies of petroleum had to be obtained. As regards roads, there were none in Persia anywhere, except a few short ones near the towns and those which the Company had itself made. He had travelled over a thousand miles of the country which they had seen in the photographs, and enjoyed the travel immensely, although it was in the depth of winter with frequently 5 ft., 10 ft. and 20 ft. of snow. From the point of view of either climate or roads, he did not think anyone who had any adventurous spirit at all would regard it as a hardship to work in Persia. He was sorry that Mr. Cunningham Craig was not present, because he believed he could have given some interesting views on the papers that had been read. He was sure they had all derived a great deal of useful knowledge from them, and from the discussion, and he asked the meeting to record a hearty vote of thanks to the authors for having so ably given the members of the Institution the benefit of their special knowledge of the Persian oilfields.

The vote of thanks was most cordially responded to, and the meeting closed.

Sir Boverton Redwood subsequently wrote as follows:—

To my great regret I was prevented by official duties from being present at the meeting on the 15th inst., but I have since read the paper contributed on that occasion by Mr. Busk and Mr. Mayo, and I should like to be permitted to place on record my high appreciation of its value, and of the public-spirited action of the directors of the Company in allowing it to be published.

I do not think I have ever read a geological statement so lucid and altogether so admirably phrased. Mr. Busk refers to the work described as having been, for the Company's Geological Staff, an

entrancing study; I may add that I have found the record of the results of absorbing interest.

Mr. E. H. C. Craig subsequently wrote as follows:—

I very greatly regret having been unable to be present at the reading of what I am sure will be recognised as one of the most valuable and most original geological papers that has ever been presented to the Institution.

I wish to add my testimony to the brilliant geological work that has been done by the authors and their colleagues in Persia. Not only is the paper a valuable contribution to petroleum geology, it is also a remarkable study of tectonics, and as such will be of permanent value to the science.

During my short visit to Persia in 1907 I was able to touch upon some of the problems which have been so successfully solved by Messrs. Busk and Mayo, and was able to identify one or two of the great dislocations, but during the course of hurried traverses without maps I had neither the time nor the opportunity to determine their hades nor their structural significance. I must confess that I was often sceptical as to the structures shown by the authors in map and section, but their work is so thorough, and their grasp of the subject so broad, that I have gradually come to accept their views of the main tectonic features.

With regard to lateral variations and the extent of the oil-bearing belt there is still much to learn, and possibly I may take a somewhat different view from that of the authors, but these are matters which will be resolved in due time.

I cannot agree with Dr. Pilgrim about the accumulation of the gypsum beds; there is much evidence of desiccation in the Fars beds, red-stained sediments and beds of rock-salt amongst it, not to mention the dolomitisation of detrital limestones. These strata were deposited during a time of fairly active earth-movement, through not such violent and extensive movement as that of post-Bakhtiari times, and desiccation of basins naturally took place while normal marine sediments were being deposited in other areas. This accounts for variation in the thicknesses and lithological characters of groups of strata.

As regards the Pusht Tumba beds, and the remarkable circular areas in which they occur, I think it will be proved eventually that Mr. Busk's first theory comes nearer to the truth than that expressed later. Those beds seem to be purely local developments, and to be associated with vertical uplifts and later with subsidence of the nature that has been described as "cauldron subsidences."

But the most remarkable feature of the paper is the demonstration that in a Tertiary series rapid earth-movement can produce structures, on a smaller scale it is true, such as we are accustomed to deal with among metamorphic rocks in the Highlands of Scotland. In Persia the plastic property of a gypseous series has emphasized some of these effects, but they are essentially similar to many structures that I have had to elucidate and map in a metamorphic massif.

Thirty-Third General Meeting.

This Meeting was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C. 2, on Tuesday, 19th November, 1918, Mr. Charles Greenway (President) occupying the Chair.

The Members of Council present were Prof. J. S. S. Brame, Messrs. Andrew Campbell, Arthur W. Eastlake, T. C. Palmer and Sir Boverton Redwood, Bart. A letter of regret for unavoidable absence was received from Dr. F. Mollwo Perkin.

The Hon. Secretary (Mr. Arthur W. Eastlake) announced that the following gentlemen had been elected:—

As *Members*:—Henry Vail Dunham, William Lee, Trevor Phair Perrott (transference from Associate Member), Abraham James Sear, Pedro Leopoldo Sol, and Martin Lewis Thomas.

As *Associate Members*:—Henry Gould Busk, Herbert Theodore Mayo, George Frederick Robertshaw, Augustin Rosas (transference from Student) and George Woodward Turner.

As *Students*:—William Alexander Montagu and Hrand Sarkis Mosditchian.

The following paper was read:—

The Motor Fuel Problem.

By W. R. Ormandy, D.Sc., *Member*.

The papers which have hitherto been read before this Institution have been for the most part records of work actually done by the writers. The present communication can make little claim to originality. It is an endeavour to bring before your notice in an orderly form some of the more important aspects of a subject the importance of which has hitherto been largely overlooked.

Prior to the war the user of motor fuel accepted his fuel much as the users of petroleum lamp oil for illuminating purposes had accepted theirs, namely, as a matter of course.

The Motor Industry.—In the whole range of commercial development few things are more astonishing than the extraordinary way in which one of the world's greatest industries has been built up on a foundation about which so few enquiries have been made. It is perhaps permissible at this stage to devote a little space to a consideration of the industries employing motor fuel. It is very difficult to obtain authoritative figures regarding the capital employed in the motor industry, by which is meant primarily the industry directly concerned in the manufacture of motor bicycles, pleasure motor cars (so called), and heavy motor transport vehicles such as motor 'buses and motor lorries. It will, however, be a conservative estimate to assume that the wages paid annually in this country by firms to men employed only in the manufacture of such motor vehicles as are above referred to exceed £10,000,000. This takes no cognisance of that vast array of dependent industries which of necessity surround and accompany a complex industrial operation such as is involved in the manufacture of the completed motor car. Among such subsidiary industries more or less entirely dependent on the parent industry may be mentioned the manufacture of magnetos, tyres, dyed leather and pegamoid, coachwork, springs, lamps, speedometers and accessories generally. The amount of aluminium, rubber, steel, leather, etc., employed must in itself constitute a considerable total. The repair, upkeep and accommodation of hundreds of thousands of motor vehicles brings in its train the necessary employment of a large number of people both directly and indirectly. It is practically impossible to estimate the capital involved or the wages paid annually in the subsidiaries arising out of the main industry.

It has been stated that there are about five and a half million motor vehicles in the United States of America, and so far from the road motor there being considered as a luxury, it is regarded in much the same light that a bicycle is regarded in this country, namely, as a necessity and a convenience of every-day life.

One would naturally assume that the fuel which is essential to the development of such an industry would have received and would continue to receive the closest and most careful attention of those in charge of the industry. Nothing is further from the truth, and it is for that reason that the title of this evening's paper was chosen as "The Motor Fuel Problem."

From time to time the Motor Press have urged that both the users and manufacturers of motor cars were living in a fool's paradise, but for the most part these warnings have synchronized with alterations in the price of motor fuels.

Too many people still regard the motor industry as synonymous with the production of what have been called luxury vehicles. In the early days of the development of the industry the motor car was undoubtedly a luxury, and it is the money provided by the wealthy user of the early days which has led to the development of the present wonderfully flexible and efficient vehicle. As before stated, the Americans regard the motor car as an industrial necessity, and it is claimed that one half of the total number of motor vehicles in the States are used in connection with farming, forestry, mining and stock raising.

Growing uses of motor fuels.—The use of motor fuel, however, is not confined to motor vehicles classified under the heads already referred to. If one thing arises more clearly than others out of this tragic war, it is the world's necessity in the future to take increased advantage of every possible means of displacing direct human agency with the object of increasing output per head of the population. Agriculturists have discovered the value of motor ploughs, and fishermen the value of motor-propelled boats. In the difficult times lying immediately before us, the workpeople of this country, and it is to be hoped other, continental countries, intend to live on a higher plane than has hitherto obtained. The days of the 12s. a week farm labourer and the 18s. a week industrial labourer should have gone for ever, but the payment of increased wages can only be obtained as a result of increased output. In agriculture, which even before the war was in this country by far the greatest of all industries, and which we hope will be a much greater one in the future than it has been in the past, it is primarily to the internal-combustion engine that we must look to reduce the drudgery of farm labour, and to enable that output to be gained which will justify the payment of higher wages without penalising the general populace by unduly increased prices. In agriculture as in every other industry the question of transport is of paramount importance, and here again it is to the motor vehicle that we must look for help, particularly if such co-operation can be brought about in this country as has long obtained in Denmark, and generally on the Continent. With the growth of wages, here and elsewhere, there will arise an increased demand for cheap motor vehicles, and there is no reason that one can see why the ratio of motor vehicles to the number of the population should not be as great in this country as it is in America, where there is stated to be one motor vehicle to every thirty persons. In whatever direction one may look, the field for the development of internal-combustion engines is growing. The aeroplane will

undoubtedly become a factor of importance in our daily life, and when one considers that a Handley-Page machine consumes some 40 gallons of motor-spirit per hour, equivalent to the demand of 40 ordinary cars for the same period of time, it will be seen that the calls upon the motor fuels may increase in a geometrical ratio. Had there been no war, the probable requirements of motor spirit alone in this country would now have been about 200,000,000 gallons per annum. This growing demand for the convenient high-speed internal-combustion engine is found all over the world, and is not peculiar to this country only.

Enough has been said at any rate to demonstrate that rapid as has been the increase in the demand for motor fuel during the past decade, there is every prospect that this demand will grow in an ever-increasing degree in the immediate future.

Fuel supply.—Let us now turn to the other aspect of the question, that is, the fuel supply. We will deal in the first place with those fuels with which the public are most familiar, namely the petroleum products. In the early days of the industry practically the only source of supply of what was known as petrol was the United States. About 1907 the demand for volatile fuel in America grew to such an extent that the home production could hardly keep pace therewith, largely in consequence of the falling off of the supply from one of the American fields which was richest in volatile constituents. Other foreign oilfields were fortunately able to fill for us the gap left by the diminishing American supply. By the utilisation of cracking processes, and by the recovery of spirit from the natural gas of America, the position was once more relieved. It is under any circumstances difficult to obtain accurate statistics as to the world's output of volatile motor fuel, and to-day even if one had the information it would not be politic to make use of it. There are, probably, some present to-night who from their position as Government servants, and as experts in petroleum questions have this knowledge in their possession. It may be that for a number of years the supply will be adequate to meet the demand, however rapidly this may grow, but I venture to think that the interest which America is taking in the question of petrol substitutes is strong evidence that there, at least, they realise the dangers that lie before them. If this is true of America, where practically two-thirds of the world's production of petrol is obtained, surely it is in order to use the word problem when speaking of the motor fuel position for those who, like ourselves, are practically dependent on outside sources of supply. Charity begins at home, and when the shortage arises it is the outsider who will feel the

pinch. It is true that new sources of oil are from time to time discovered, but at the same time old oilfields cease to yield. The new oilfields have not on the whole proved as rich in volatile constituents as were the old ones, and not all oils are equally susceptible to cracking processes. Perhaps Sir Boverton Redwood will give us an expression of his opinion as to the relation likely to exist in the near future between the supply of and demand for volatile fuels. In my opinion it can only be a question of time, and no great length of time, before there is an actual world shortage. Long before we arrive at a period of actual shortage, prices will increase, and the fuel will tend to flow towards the market which brings the highest return, unless the producing countries protect themselves by special legislation. Those sources of supply, such as Burma, Persia and Mexico, with comparatively small home markets, will tend to send their products to the market which brings in the highest yield. We have a great industry almost entirely dependent on fuel which comes from sources outside our own control. It needs no argument to support the view that a huge and important national asset like the motor industry should as far as practicable be independent of outside sources. The last few years have shown us the danger that may reside in dependence on sea-borne traffic. If we must be dependent on extraneous sources of supply, these should so far as possible be controlled within the Empire.

It is not proposed at this point to say anything regarding the financial aspects, as these will be better discussed after a consideration of the various proposed substitutes for the petroleum products.

Motor Fuels, Solid.

We will divide motor fuels into the three physical groups of solid, gaseous and liquid, and consider these in turn.

1. *Coal.*—Here coal, coke, and charcoal come under consideration. The use of coal, particularly of the bituminous type, is associated with so many difficulties, and its by-product coke is so readily obtainable, that it need not detain us long. It is conceivable that the internal-combustion engine of the future may be driven by gas generated from solid fuel in a producer, but the difficulty associated with the use of bituminous coal in gas producers have hitherto prevented this type from becoming popular even for the stationary suction or other gas-producer plant, and for the portable engine these difficulties are greatly enhanced. Even for use as a generator of heat for steam-raising in motor

tractors, bituminous coal has many drawbacks. The last word has probably not been said regarding steam-driven motors. In spite of competition the Clarkson steam motor-'bus has held its own, and until recently these ran on paraffin as a fuel. Owing to the shortage and the high price of this fuel, Mr. Clarkson has directed his ingenuity to the production of a coke-fired boiler, and I believe with every prospect of success. It would not appear that even for heavy motor-vehicles, the steam-engine and boiler would oust the internal-combustion engine. If the price of fuel for the internal-combustion engine becomes excessive, the steam-motor may have a new lease of life, but this will be accompanied by an entire revolution in the existing trade. On the other hand, for small stationary engines and heavy motor-vehicles, and possibly for motor boats, there would seem to be at any rate a prospect of success for the internal-combustion engine driven by some form of suction gas, but to generate such gas a solid fuel free from tarry constituents must be employed, owing to the difficulty introduced in washing the gas.

2. *Coke and charcoal.*—Here coke and charcoal alone come into question. Ordinary wood charcoal is expensive, and, owing to its bulk, inconvenient to store, but charcoal produced from the woody lignites found in Ireland would seem ideal for the purpose in view, and it is not impossible that some form of compressed peat charcoal should prove of value in this respect. Though solid fuels in suction or other gas producers are likely to be of growing importance to stationary engines, and possibly even to the larger sizes and heavier types of portable motors or for boats, there would seem little prospect of these being of direct help in assisting the existing motor industry, in development along normal lines with the existing type of engines.

Gaseous Fuels.

The motor industry has known for a considerable time that ordinary coal gas worked efficiently in their high-speed engines, and it has become quite customary to use town's gas for running motor engines on the bench. The shortage of petrol brought about by war requirements has led the general public to turn their attention to the utilisation of town's gas as a fuel for driving motor cars. It has been found that 250 cubic feet of normal town's gas are equivalent to a gallon of petrol. As a temporary measure, balloon-like structures have been employed to carry a few hundred feet of gas, particularly for vehicles employed in town-service, and for those making a limited run, but this is

obviously a makeshift policy. The development of the utilisation of town's gas is dependent upon the discovery of some suitable container capable of holding the gas under a considerable pressure so that the volume and weight of the container shall not be unreasonable. The use of coal gas necessitates practically no change in the existing engine, and the fact that England possesses a more widely distributed coal-gas manufacture than any other country in the world, points to the advisability of developing the pressure gas-container at the earliest moment. The Government have recognised the importance of this matter, and have a Committee which is doing valuable work upon the subject, under the chairmanship of Sir Boverton Redwood.

Liquid Fuels.

The paraffin series of liquid fuels can be divided into three groups. First, the more volatile portion known under the general name of petrol, used in high-speed internal-combustion engines; second, what is generally known as paraffin oil, such as is used for illuminating purposes, employed in marine motors and generally speaking where wide and sudden variations of speeds are not constantly required; and third, solar or fuel oil, being the fraction boiling at a higher temperature than paraffin, used in Diesel or semi-Diesel engines, and, as the name implies, as liquid fuel for steam raising.

Substitutes for Petrol.

The most important of these is undoubtedly the volatile fuel, and we will review the materials which have at one time or another been proposed in substitution. Of the home-produced materials which can serve as an alternative to petrol, the coal-tar distillates must first receive consideration. That what is known as benzol can be used in the ordinary motor-car, with the most trifling alterations to achieve the best working results, has been demonstrated beyond all question.

(*a*) *From Coke Ovens.*—During the distillation of coal, either for the production of coke, as in the coke oven, or primarily for the production of coal gas, certain more or less volatile products are evolved known as coal tar-distillates. Coke is required in large quantities for the production of pig iron. Up to comparatively recent years such coke was formed by heating coal in bee-hive ovens, the heat for the distillation being provided by the combustion of all the volatile products. These have been largely displaced by the so-called byproduct-recovery coke-ovens, which

are simply huge horizontal retorts heated by means of the gas produced in the distillation of the coal. The gases evolved from these ovens, like the casing-head gas of the petroleum fields of America, contain volatile liquid fuel, there being from 1½ to 3½ gallons of liquid fuel in the gas produced from each ton of coal carbonised. Owing to the Government demands for these volatile liquids, most by-product coke-ovens have the necessary plant for their recovery.

(*b*) *From Gas Works.*—When coal is distilled in the smaller retorts employed in the manufacture of coal-gas, the products of distillation on cooling result in the production of what is known as coal-tar. On subsequent fractionation this coal-tar yields a small proportion of volatile liquids, and a much larger proportion of oils, to which reference will be made later. Just as the gas from the coke-ovens contains volatile liquids, so the coal-gas hitherto supplied to the public has contained similar bodies. The enormous war requirements for benzol and toluol have led to plant being installed at most of the large gas-works for the recovery of these particular volatile liquids, and anything from one to two gallons per ton of coal carbonised may be recovered in this wise. As probably only the Government officials have accurate information as to the total amount of benzol which is produced by the washing of coal-gas, it is impossible to give more than a rough estimate as to the amount of volatile liquid coal-tar distillates produced in this country per year, but we may assume that under post-war conditions something approaching 50,000,000 gallons per annum will be available for all purposes. One-half to two-thirds of this will be produced in the approximately 9,000 coke-ovens now in operation. If the much-talked-of central electric power-stations come into being, these may receive their energy in the form of gas made in byproduct-recovery producer plants, in which case they would add something to the fuel supply, but very much less than if the same amount of fuel were coked or converted into coal-gas along the ordinary lines.

2. *Shale Oil.*—In many parts of Great Britain large deposits of bituminous shales are to be found. In the neighbourhood of Edinburgh, a comparatively large industry has arisen from the distillation of these shales. They yield sulphate of ammonia (a valuable fertilizer), and a range of liquid products running from a volatile spirit to a heavy lubricating oil. Compared to the home-requirements, the total yield is at present comparatively small, but there are immense deposits running from Norfolk down to Dorsetshire which are practically untouched. It is true that

these more southern shales are badly contaminated with sulphur compounds, but there is no reason to believe that the problems involved in obtaining a marketable product are insuperable. Better and fuller utilisation of all such available oil-shale deposits, and the working up of low-grade cannel and coals, must receive a degree of attention in the future which they have escaped in the past. Any product required to displace petrol must be capable of production in very large quantities, and within a certain range of prices. These two requirements limit the field of possibility, and with the exception of products produced from the distillation of coal and shale, the only substitute which has hitherto warranted serious consideration is alcohol.

3. *Alcohol.*—At first sight no product would seem less likely to meet the required conditions. Hitherto in this country alcohol has been decidedly an article of luxury. Compared with benzol and petrol, its combustion is attended by a comparatively small evolution of heat, and finally it is not by any means so readily inflammable. That alcohol can be produced in practically unlimited quantity is certain, and that in spite of its lower heat-value it can be efficiently employed under certain conditions in the existing type of engines has been demonstrated with equal certainty. Very few questions of like national importance have been so prejudiced by the well-meant but ill-advised efforts of its friends. Alcohol can be produced from materials containing sugar, starch or cellulose. Practically all sugar- and starch-producing materials which are grown on a sufficient scale to be worthy of consideration are employed for food-purposes, and their utilisation at the present moment can hardly come into consideration, but under post-war conditions, there are many parts of the British Empire where the production of industrial alcohol might be carried out on an enormous scale, greatly to the benefit both of the local population and the Empire in general. It has been stated that if 5 % of the grain crop of the United States were converted into alcohol the product would suffice to displace the entire American demand for petrol. There have been many attempts in this country to awaken an interest in the subject of industrial alcohol production on a large scale, but generally speaking it may be said that the user, that is the motoring public, have hitherto been too scattered and divided to take any serious action, and the motor manufacturer appears to have regarded it rather as a matter for the motor user, whilst the Government appear to have been guided almost entirely by the scientific experts of the Excise Department.

(*a*) *From Sugar.*—Alcohol can be cheaply produced from molasses

or the non-crystallisable residues from the manufacture of cane- or beet-sugar. On the Continent, particularly in France, very large quantities of alcohol are produced from the beet-sugar residues. If this country is to persist in its present agricultural policy, and to grow increasing amounts of grain, crop-rotation will necessitate a great increase in the production of root crops. If the grain-output is to be doubled or trebled, the necessary root-crops, if we are to stick to those at present employed, would lead to a great overproduction of mangolds and turnips. The cattle of the country could hardly be expected to increase in the same ratio as the grain output, since the increase in arable area must be produced at the expense of pasture lands. It has been demonstrated times without number that the sugar-beet can be grown in this country to give as heavy a yield, with as high or a higher sugar-content than is obtained on the Continent. If the farming community could be persuaded to co-operate, as is done on the Continent, there is no reason why the increase in root crop required should not be sugar-beet, which is if anything a better cleaning crop than any of its possible competitors. We should then be able to produce some proportion of the home requirement for sugar and from the residue obtain industrial alcohol. In all cane-sugar growing areas very great quantities of molasses are produced, and in many districts these have hitherto been regarded somewhat in the light of an inevitable evil. Some 15 years ago it was reported that a crude 95 % alcohol could be produced in Demerara at less than 6d. per gallon. Although these sugar-cane residues amount in the aggregate to a considerable quantity, they would not under any circumstances produce alcohol in quantities which would enable us to regard it as a possible competitor with petrol. If on the other hand a wasted by-product at these various centres could profitably be converted into a much-required and easily transportable valuable fuel, we should be assisting the home market, and at the same time be strengthening the position of the sugar growers. In India alcohol has been produced for many generations from the flower of the Mowrah tree, which in the dried form contains up to 60 % of sugary matter. The pronounced tendency to industrial development in India makes it possible that this source of alcohol may be exploited to the full. There is no question whatever of this source of supply being adequate to meet the Empire's demand for volatile fuel, but, as in the case of the residue from sugar-making, it might add its quota of a few million gallons per annum, and probably the fact that alcohol was being produced in many centres would eventually prove an additional advantage.

(*b*) *From Starch.*—The greater part of the alcohol hitherto produced in the world has been made from some form of starch. In Germany, for economic reasons, the potato has served as the main source of starch for the production of alcohol. In France the sugar-products have been more called upon. In America the national crop maize has served as the main source.

(*c*) *From Potatoes.*—Probably more has been written about the possibility of producing alcohol from potatoes in this country than any other aspect of the question, and only too often the state of affairs obtaining in Germany has been quoted or rather misquoted in connection therewith. Alcohol was not produced from potatoes in Germany because this was the cheapest supply, having regard merely to the production of alcohol, but because it was regarded as the most economical from a much wider national standpoint. Imported molasses, imported maize, beet-sugar residues, and many other products would have been cheaper to employ, but their use would not have encouraged home agriculture, it would not have enabled hundreds of square miles of sandy country to carry an agricultural population, and, above all, it would not have enabled the country to build up a food reserve which, as this war has shown, has absolutely saved the country from starvation. By a very ingenious series of laws the German Government encouraged the growth of potatoes, and the conversion of these into starch and alcohol at innumerable small starch works and distilleries scattered over the country. The conditions under which a distillery might exist necessitated that the farmer producing the potatoes should carry sufficient cattle to consume the schlempe or distillery residue, and that the manure from such cattle should go back to the potato land. Taxation was so graduated that the small distillery could live in spite of the competition of the highly-capitalised large central distillery, but it does not follow that what was possible in Germany would be advisable in this country. The whole question requires the most painstaking investigation. It is true that the average price obtained in Germany for alcohol-potatoes was only about 22s. per ton, but the farmer obtained distillery residue for his cattle, and he and his men worked on the distillery during the slack winter months. It is not entirely a question as to whether it pays to grow potatoes for sale at 22s. per ton, but whether this, in conjunction with the value of the residue, the wages obtainable from the distillery in the winter, and the profits arising from a share in the distillery, render the whole series of operations a profitable one. The case is very well put in a pamphlet on industrial alcohol by R. N. Tweedy,

but unfortunately some serious errors have crept into his summary and conclusions. If potatoes are to be sold to the distillery at £3 10s. 0d. per ton, there can be no question of the production of industrial alcohol from potatoes, for the yield does not exceed an average of 20 to 25 gallons of 95 % alcohol even from the special variety of potatoes rich in starch grown for this special purpose on the Continent. The statement that in Ireland they could obtain 150,000,000 gallons of 95 % alcohol from 2,500,000 tons of potatoes is obviously wrong. It is very doubtful whether more than 50,000,000 gallons would be obtained for a long time to come from the weight of potatoes in question, for the average starch-contents of the English potato is probably nearer 17 % than 20 %. Owing to the much higher percentage of starch contents in grain, the yield of alcohol per ton of grain is very much greater than is obtained from potatoes. From maize containing about 60 % of starch, about 75 gallons of alcohol per ton may be expected, but it is obvious that the home country was never intended by nature as a cheap producing centre for a product like alcohol produced from starch and sugar. It is to warmer and sunnier climates that we must look. Some seven or eight years ago it was reported that maize could be grown in almost unlimited quantities in some of our South African colonies at a price not exceeding £1 per ton, that is 20s. for the raw material for the production of 75 gallons of finished spirit equalling approximately 3¼d. per gallon for the raw material. The Australian Government are considering the question of industrial alcohol very seriously, and are examining various hitherto wasted natural products, as well as those which may require cultivation. Their situation, distant from the oil-fields, makes it the more imperative that they should endeavour to become self-contained, and in spite of the high cost of labour it is probable that somewhere within the limits of their enormous country it will prove possible to grow raw material for alcohol production at a price which would enable them to become independent.

(*d*) *From Cellulose.*—It has long been known that alcohol can be obtained from cellulose materials by the conversion of the cellulose into fermentable sugars by the action of acids. This, known as the Classen process, has been experimented upon on a commercial scale in the western states of America. Great technical difficulties were experienced in the early stages, but during recent years the discovery of suitable linings for pressure vessels, capable of resisting acids, has awakened further interest in this promising line of investigation. It is reported that 30 to 40 gallons of com-

mercial industrial alcohol can be obtained from each ton of wood treated. As this result is still very far removed from that theoretically possible, there is every hope that in the near future much better results will be obtained. Certainly experimental work along these lines should be pushed forward, because if forestry is to receive the attention in this country which it has received for generations on the Continent, there will be ever-growing supplies of small wood for which no better outlet than the production of industrial alcohol can be asked.

(*e*) *From Sulphite Wood-Pulp Residues.*—In the manufacture of the high-grade wood-pulp for the manufacture of paper, known as sulphite pulp, enormous volumes of hitherto waste-products are produced. Sulphite pulp is produced annually in hundreds of thousands of tons, and when we consider that this output only represents about one-half of the solid contents of the wood employed, it is clear that the utilisation of the residues is of great importance. The treatment of the wood for the manufacture of sulphite pulp is in its nature somewhat allied to the Classen process referred to above, and it is not therefore astonishing to learn that the waste liquors contain large quantities of fermentable sugars. Processes for the recovery of these sugars by conversion into alcohol have been worked out on a large scale in Norway and Sweden, and many large factories are already installed. It is expected that both Norway and Sweden will render themselves entirely independent of outside sources of supply of motor fuels by utilising the whole of their sulphite pulp residues. It is estimated that the residues from the Norwegian sulphite pulp factories will provide 4,000,000 gallons of alcohol per annum, and Sweden, already producing nearly 4,000,000 gallons per annum, has plant in process of erection for the production of a further 3,000,000 gallons. It is obvious that this method of producing industrial alcohol is of comparatively little interest to this country, but it opens out great possibilities for our colonies, such as Newfoundland, Canada and India, where the production of paper-making materials goes on at an ever-growing rate.

(*f*) *By Synthetic Alcohol.*—Synthetic processes for the manufacture of alcohol from ethylene and acetylene have been developed, and their ability to compete is largely bound up with the cost of those chemicals, serving as a starting point for the reactions involved. Acetylene is made from calcium carbide, and this is produced in electrical furnaces from mixtures of coke and limestone. It is only in countries where electricity can be generated at a very low price, that this process can hope to compete, and here again the

home country is handicapped by nature. It is to India, Canada and Africa that we must look for products dependent upon electricity produced by water power. It is reported that the French Government intend to put down plant for the manufacture of many millions of gallons of alcohol per annum from calcium carbide produced by water-generated power, and the results of their large-scale work should be watched with the greatest interest.

Alcohol as a Motor Fuel.

That alcohol can be produced in many parts of the British Empire at a reasonable price is obvious from what has gone before, and it now remains to consider briefly in how far alcohol can be used as a substitute for petroleum products. Prior to the war there existed thousands of alcohol engines on the Continent for the most part employed in agricultural work. These were chiefly stationary engines, designed with a long stroke and a high compression, and provided with means for heating the fuel or the air-supply for starting purposes. Further proof in this direction is not required. It is interesting to note that the thermal efficiency of these engines is so much higher than that of petrol engines that the fuel consumption per brake-horse-power hour is practically equal in the two cases, though the heat-value of the alcohol is not quite two-thirds that of the same weight of petrol. Moreover, experience has proved that there is no special corrosion arising from the production of acid products, as to which such a cry has been made.

The problem which meets us in this country is the provision of a motor fuel which shall be applicable to the hundreds of thousands of existing motors, and it is undoubted that alcohol without some admixture cannot be thus employed. We have seen that there is a home production of approximately 50,000,000 gallons per annum of coal-tar distillates. This motor benzol will mix with alcohol in any proportion, and experiments have shown that one part of benzol mixed with two parts of alcohol can be employed in existing engines without any alteration whatever beyond arranging for the better heating of the air-supply to the carburetter, and possibly a slightly larger jet. Such admixture not only shows a higher thermal efficiency than either constituent alone, but an engine provided with such admixture runs more smoothly than if petrol were employed. If 100,000,000 gallons of alcohol per annum were available, this, mixed with the 50,000,000 gallons of benzol would provide us with an amount of fuel which would go far towards meeting immediate requirements. Should the demand for this mixed fuel increase at a rate so great that the

supply of benzol became inadequate, we have a ready means available of supplementing it by the production of an ethyl ether by a simple industrial operation from the alcohol itself.

Benzol Supply.

Let us now consider the possibility of an increase in the supply of benzol. The number of coke-ovens employed is dependent upon the country's production of pig-iron. Prior to the war the German production of coke was about three times that of this country. During the ten years prior to the outbreak of the war the German output of coke increased from 12,000,000 tons to 32,000,000 tons, and in the same period the English production remained practically stationary. In the post-war period we may hope that this state of affairs will no longer obtain, but it must be recognised that so far as regards coke-oven benzol, this, in the eyes of the steel world, is a very minute by-product, and that no variation in its price will have any appreciable influence upon the amount manufactured. As regards gas works, it is certain that the utilisation of coal gas in industrial and heating operations will continuously grow, and in so far as this is the case there will be an increased output of motor benzol. It is however to the better utilisation of hitherto neglected low-grade cannel and other coals that we must look for additional outputs. In the lean years to come the question of cheap power must be ever before us, and the cheap power is undoubtedly bound up most intimately with the utilisation of cheap and hitherto wasted materials. There is no doubt that it is a national duty that adequate experiments should be carried out with a view to discovering the proper method or methods for obtaining from low-grade fuels the utmost values contained in them, and it is to be deprecated that the interest recently aroused in this subject should have been brought to an untimely end. The offers of many wealthy colliery firms to carry out experiments received something more negative than mere lack of encouragement.

The more the position is looked into the more complex are seen to be the relations which obtain. The production of benzol from the coke-oven is primarily dependent on the growth of the iron and steel industry, and whether the coke-ovens installed shall put down benzol-recovery plant depends upon the market value of the product, for there is a price below which it does not pay to extract. Similarly, the utilisation of low-grade fuel depends upon the market for power, and the relative amounts and values of the sulphate of ammonia and other volatile products obtained

therefrom. The production of alcohol, as has been seen, is very frequently bound up with complex agricultural questions, such as the relation of crop-rotation, the carrying of stock and the value of residuals. Whether the gas works will continue to extract benzol and toluol from the town's gas depends to some extent upon the value of the extracted fuel, but also upon legislation dealing with the nature of the gas which the companies are to be allowed to sell. The incandescent mantle has so revolutionised lighting that it would appear that the time has come when gas should be sold upon its heating-value rather than upon a candle-power basis. If this heating value is not set at too high a figure, and the candle-power restriction is removed, the gas works will be readier to continue to strip the benzol. The utilisation of vertical retorts working at a high temperature, with simultaneous steaming of the retorts, will lead to an increased production of volatile fuel. This will resemble paraffin rather than the aromatic compounds. Though this will introduce new problems for the tar distiller and the refiner, the fuel produced will be in every way applicable to the motor industry.

Distribution.

Every motor user is aware of the fact that the specific gravity of petrol has been increasing for a number of years. In the early days when carburetters were somewhat primitive, a ·680 to ·690 fuel was essential. The increased demand has led to the necessity on the part of the petrol producers to cut at a higher temperature, giving a larger yield of liquid of a higher average boiling-point and a higher specific gravity. In order that a motor shall start with reasonable ease there must be a certain percentage of constituents of low boiling-point. It is obvious that the petroleum people will desire to obtain possession of the benzol supply of this country. In admixture with their own product, it will enable them to make use of large quantities of even higher boiling-point constituents, to which the benzol would serve as the ingredient of low boiling-point. The petroleum firms can say, and rightly, that they would be able to mix the benzol with petrol to form a standard fuel, and that they have a marvellous organisation for distribution at their disposal. The benzol-producers, who are highly organised, are faced with this position. They might sell their whole production to the petroleum people at a price to be agreed upon, or even upon a sliding scale, when the worrying question of distribution would be taken out of their hands. On the other hand their material is produced already at a very

considerable number of centres, and to this extent the problem of distribution is simplified. It is obvious that the producers of 50,000,000 gallons per annum of motor benzol cannot hope to control prices with a demand for motor fuel of 200,000,000 gallons. The petroleum firms are corporate bodies existing with the object of making profits, and they have stated that the market value of petrol is the last halfpenny that the public will pay for it. Ignoring benzol, they control the situation, and the only limit to the price they can exact is that which renders them unable to sell all their product: the user is simply a lamb to be shorn. In the history of the motor industry, there have been periods of low prices, when the various petrol companies were fighting among themselves, but in the end the users have had to make good the losses thus incurred. So long as trade is run on individualistic lines, this state of affairs will continue, and I question if there is anyone present who being a large shareholder or a director of a petroleum Company would act otherwise, but occasions arise where national interests must take precedence. Conceive a situation to arise where the world's demand for volatile motor fuel exceeded the world's supply. The wealthy motor-car user and the wealthy industry would continue to purchase at ever higher prices, but the middle classes and the working man and the smaller industries working on a narrow margin would cease to use motor-vehicles. The development of the motor industry would be retarded or would cease. Motor transport, which is vital to every industry, would suffer and in the years to come there is little doubt that agriculture, which by then will be largely dependent on the internal-combustion engine, would also feel the situation.

Enough has been said to show that alcohol can be produced within the confines of the British Empire in practically unlimited quantities, but the only immediate way to encourage the use of alcohol is to use it in admixture with home-produced benzol. It is not to be expected that if the petroleum people obtain control of the benzol supplies, they will wish to encourage the production of a fuel which, capable of unlimited expansion, will put a definite limit to the price which they can obtain for their competitive material. Altruism is sometimes found in individuals and in small firms but it is an unknown term with large corporations. It would appear, therefore, to be desirable on most grounds that the supply of home-produced fuels should not pass into the hands of its petroleum-controlling competitors. The by-product coke-ovens in this country are for the most part owned by wealthy colliery and iron and steel firms who are quite capable, from the

financial side of handling the benzol proposition, but the crux of the problem lies in the question of distribution. It is here that the motor industry and the motor-using public can step in. Once the benzol supply gets into the hands of the petroleum people, the chance for the development of an alcohol industry is retarded, and progress put back for years. If the motor industry, that is, the producers and all allied trades dependent upon them, and the motor-users are convinced that there is a motor-fuel problem, and that its solution is of vital importance, now is the time to act. It is probably within their power to make such arrangements as shall secure the benzol supply as a purely national asset. It may and it will be urged that if the motor-user and the motor-maker join in some scheme with the benzol producer for the purchase and distribution of the home-made fuel, the prices of petrol may be lowered against them. It is still more certain that if they do not take this action, the price will be raised against them. If they are not prepared to make some sacrifice, and to run some risk to secure the fuel which is at present made in this country, not only for its immediate benefit but with a view to all that it may mean hereafter, they will have no legitimate grounds for complaint, whatever may happen in the future. One of the great difficulties in the past has been the lack of unity on the motorist side. The great organisations of motor-users, the Royal Automobile Club, the Automobile Association and Motor Union and the Auto-Cycle Union, have not pulled together, nor can it be said that the motor manufacturers have exhibited a united front. The war has opened our eyes to many things. The nerves connecting the outlying portions of the British Empire were becoming atrophied, but the efforts of the last four years have brought about a healthier and closer union. In all directions the need for greater unity of action has become apparent, and it will be lamentable if petty jealousies are allowed to interfere with that unity among the motor-makers and users which alone will enable them to overcome the difficulties which lie before them.

No imaginable increase in any of the industries that lead to the production of motor-benzol can conceivably give an increased yield which will keep pace with the ordinary growth of motor-fuel requirements. Still less can they lead to such a production as would enable our total requirements for motor-fuel to be met. If we could look forward to using a fuel composed as to half or more of alcohol, the benzol supply, aided by a certain amount of ether produced from the alcohol, would probably enable us to keep pace with the growing requirements. There are, of course, many

aspects to the fuel problem which we have not yet touched upon. Recent experimental work goes far to prove that the high-boiling-point coal-tar distillates are in many respects much more tractable than the paraffin bodies of an even lower boiling-point. The coal- and gas-producer tar produced in this country yield about 130 million gallons per annum of these heavy oils. Great quantities of these are being used for Diesel engines, as well as for fuel oil for steam-raising in the Navy. Certain experiments, however, tend to show that these creosote oils can be vaporised and rendered fit for use in high-speed motors, and this aspect of the fuel problem is worthy of some close consideration. The time at our disposal does not permit of a discussion of the problem of de-naturing alcohol, nor will it allow us to bring under review the Excise laws of this country, though the latter would form better subject-matter for a modern Gilbert and Sullivan.

Lubrication Problems.

The utilisation of a new fuel introduces new problems in lubrication. Many of you will be aware of the fact that attempts were recently made to use an admixture of paraffin oil with petrol for taxi-cabs in London and elsewhere. The utilisation of this mixture was accompanied by very serious trouble to big-end bearings and main crank-shaft-bearings. Certain experiments, carried out by Mr. Lester and myself, point towards the conclusion that, when using petrol as a motor-fuel, a certain amount rapidly gets into the crank-case oil, and that a state of equilibrium is attained dependent on the temperature of the crank-case oil, the amount of ventilation, and other factors. Where paraffin is employed, owing to its lower vapour-tension, much larger quantities are washed out and retained by the oil-spray in the crank-case, resulting in a diminution of viscosity of the lubricating oil, which is sooner or later attended by trouble in the bearings.

Research.

It is obvious that if attempts are to be made to utilise alcohol in admixture with other fuels, a large amount of research work will have to be done. It has been proved that alcohol is entirely satisfactory for specially-designed engines and some experiments, carried out at the cost of the *Auto-Car*, go far to prove that the modern petrol engine will work quite well on alcohol-benzol mixtures, but the best limits within which such mixtures can be employed still remain to be found out. There are problems relating

to the viscosity of alcohol-benzol, alcohol-ether and alcohol-benzol-ether mixtures, which await investigation. The vapour-tension of admixtures of various fuels is not by any means the mean of the various ingredients of the mixture. We have to find out what percentage of water can best be retained in the alcohol. Although alcohol and benzol are miscible in any proportion, that is not true if the alcohol contains more than a certain quantity of water, and the equilibrium not only of alcohol-water-benzol mixtures has to be investigated, but the possible influence of paraffin compounds and any other fuel which might have to be eventually added to the mixture.

It is stated that alcohol is not suitable for high-speed engines, and unless we are to persist in our policy of empiricism, it behoves us to learn something of the relative rate of the propagation of flame in alcohol-air mixtures, both alone and mixed with benzol, ether, etc., at ordinary, and at higher temperatures and pressures, in order that this may be compared with the corresponding figures for petrol, and that our designers may have facts and not surmises to build upon.

Looking Back.

You may say that the question of employing alcohol as a fuel has been raised many times. It is getting on for 20 years since I raised this matter at a lecture before the Royal Automobile Club, long before the Club had moved into its present palatial home. It required some courage to point out to a Motoring Association, when petrol was less than one shilling per gallon, that a time was bound to come when a petrol substitute would have to be considered. There have been quite a number of Committees formed to deal with the question, and the decision of every one has been that alcohol was the only alternative fuel in sight which could be produced in large enough quantities, and at a price which left it within the range of practical politics.

The Imperial Motor Transport Conference, at which practically all the British Colonies were represented, issued a report which may be summed up in the three words—"Develop alcohol fuel." A special Committee was formed, under the chairmanship of the Hon. Arthur Stanley, to deal with the whole subject, but the outbreak of the war scattered the members of the Committee, and put an end, for a time, to their activities. Most of the Committees were asked only to express a pious opinion, and they had no practical outcome. The fact is that none of the Committees had adequate funds with which to deal with a problem of this magnitude.

The Present Position.

It may be asked why a lecture, primarily devoted to means for finding a substitute for a petroleum product should be delivered before the Institution of Petroleum Technologists. I believe it was originally intended that this Institution should deal with matters based on the widest interpretation of the word "petroleum," and certainly the coal-tar products come within the scope of the original meaning of the word "petroleum" as being oil obtained from a rock, as geologically coal would be considered in that sense. It would be, I think, regrettable, if the scope of the Institution were narrowed by any popular misunderstanding as to the objects with which it was founded. It is much to be desired that as far as possible, papers dealing primarily with motor-fuel problems should be recorded in the proceedings of one Institution, and for that purpose this Institution will, I think, be recognised as admittedly the most suitable. It would be well if we could have communications from coke-oven experts and from gas works authorities on such aspects of those industries as bear most specifically on motor-fuel problems, but I must admit that, at present, this Institution is regarded more or less, by the scientific public as sacred to the interests of petroleum in the popular acceptance of the word. If the Institution desires to become a recognised authority for the expression of all sorts of opinions on matters dealing directly with the motor-fuel problem, the general idea of the public as to the scope of its objects will have to be altered, and the essentially non-petroleum industries, again using the word in the popular sense, should have representation on its Council. The fact that a paper of this nature has been read before this Association is some real evidence that other than the petrol side can get a hearing.

As many of you are no doubt aware, an Inter-Departmental Government Committee has been formed to deal with the whole subject of alcohol in its aspect as a motor-fuel. A Past President and the originator of this Society is the Chairman of that Committee. There has been some comment that a man who has been so intimately associated with the history of petroleum development should have been appointed to this position. I would remind you that Sir Boverton Redwood has taken an active interest in the question of industrial alcohol from the earliest days. As my chairman in 1904, he publicly urged upon the motoring fraternity the advisability of looking ahead to the times that would inevitably come when petrol would be a luxury. Again, as President of

the Society of Chemical Industry, he showed by figures the urgent need for public action in this question of motor fuels. No member of Sir Arthur Stanley's Committee put in more work on behalf of the Imperial Motor Transport Alcohol Committee than he did. As alcohol in one or other of its aspects comes under the powers of so many Government Departments, it was essential that representatives of these controlling bodies should be brought together, so that whatever decision was arrived at should be a decision of the Government as a whole, not liable to controversion by some individual Department. Surely if anyone should be in a position to realise the necessity for action in finding a petrol substitute, it must be one who has the fullest knowledge of the industry as a whole, and I personally can conceive of no reason why any person should put in the amount of work that is necessary in connection with a Committee of this description who has not the ultimate good of the community at heart. The Committees hitherto formed to deal with the subject of substitutes for petrol have not led to any practical results. I believe that the present Committee is in a position to achieve something of value, but unless it has the cordial and fullest support of the motor-industry and the motor-user I believe that its time and its efforts will be wasted. Among the duties of any body formed to enquire into the question of alcohol as a substitute for petrol is that of obtaining authoritative information upon processes and products in use and available in other countries, and particularly in our own Colonies. Such information as this is more readily accessible by a Government Committee than by one formed by the trade, but when questions of the utilisation of alcohol in conjunction with other substances come into question, experimental work is necessary. In so far as the work of the Committee is related to the production of alcohol, it is to a great extent a colonial and agricultural question. The work which would have fallen upon the Imperial Motor Transport Alcohol Committee, now falls within the scope of the Government Inter-Departmental Committee. I have no doubt that means will be found for covering the cost involved on this side of the work. It is so emphatically an Imperial question that there would appear to be every reason for looking for help to the Government, but the problem is not the same when we deal with the application of alcohol for a specific purpose. It is only under exceptional circumstances that I believe in Government subsidised research, and where an industry can well afford the expense involved in essential investigations, they will be well advised to take the matter in hand. If we assume that the Motor and Allied Industries pay

£50,000,000 per annum in wages (and this is probably below the mark) a levy of one penny per £100 paid in wages would bring in an income of £2,000 per annum. If the motor-user can be convinced that the motor-fuel problem is as urgent as I submit that it is, I am sure that he would be willing that some small proportion of his subscription to his Club or Society should be earmarked for Research work, or indeed he might agree to a small additional subscription, to be entirely devoted to such a project.

I would respectfully submit that it is the duty of all the Motor Trades Associations, and of all the Motor Users Associations, to appoint a joint Fuel Committee, which might well be made a standing Committee. I would further suggest that this Committee should employ some technical man with the widest possible knowledge of the motor-fuel problem in all its bearings, to act as their advisor, and to represent them where technical matters have to be considered. In the aggregate Motor Manufacturers and the Allied Industries and motor users together, are one of the greatest powers in the country, and a joint Committee, capable of speaking for the whole, would be able to exercise a power which is entirely lacking at the moment. Such a Committee might assist the Government in innumerable directions. It could undertake the arrangements for the carrying out of road trials.

Conclusion.

It is stated that the production of motor-vehicles in the United States during the last 12 months exceeded 1,700,000. This does not include motor-ploughs, motor-boats, aeroplanes, petrol-driven electric lighting and pumping sets, etc. Assuming that each car will consume 400 gallons of petrol per annum, we have an additional consumption of approximately 700,000,000 gallons of petrol required for the production of one country in one year. This represents roughly 2,000,000 tons, and if we assume that by modern means 20% of petrol can be obtained on an average from each ton of crude oil, an additional production of 10,000,000 tons of crude oil is required to keep on the road the production of one year's cars from America only. The last estimate I could find of the world's production of crude petroleum was of the order of 50,000,000 tons per annum. America itself, the greatest petroleum-producing country, is seriously perturbed about the situation. If we accept the present production of benzol available for motor purposes in this country from all sources to be 50,000,000 gallons per annum, we should require the output of our gas works to be doubled and our iron and steel trade to be doubled before the amount available

from this source reaches 100,000,000 gallons per annum. In view of the growing demands it is not conceivable that the enormous capital involved in the production of benzol can be got into operation as rapidly as the demand for the fuel progresses. There is no alternative at present in sight except alcohol. If the motor-user and the motor-maker (and they are equally interested) are convinced that the situation is as stated, now is the time for them to show by action that they realise the seriousness of the position.

DISCUSSION.

The President thought the members were much indebted to the author for the very able paper which he had read, but he was afraid that he did not quite agree with some of his deductions as to the necessity or importance of finding substitutes for petroleum as motor fuel. Those deductions were, he ventured to state, based to a large extent on misapprehensions or on wrong premises. In the first place, in the figures quoted the author had dealt only with the production of benzine or petrol, leaving out of account altogether that kerosene was also, as he had pointed out, largely used as a motor fuel by agriculturists and fishermen, and for lorries and 'buses, and therefore his figures appeared to need correction to that extent. The importance of the point could be best appreciated when he mentioned that the estimated consumption of kerosene to-day in this country for those purposes was something like 200,000 tons per annum, the bulk of which had been developed during the war; and so much had the use of that petroleum product extended for motor purposes, as the result of the exigencies of the war, and of the adaptation of engines to the burning of oil of a heavier specific gravity than benzine, that he estimated the consumption of kerosene for motor fuel purposes in the United Kingdom would very shortly reach a total of not less than 400,000 tons per annum, or a quantity equal to the whole pre-war consumption of benzine.

In the second place, the author estimated the world's production of petroleum at only 50,000,000 tons, whereas in 1917 it was over 70,000,000 tons, and would to-day be much larger still had it not been for the great difficulty which had been experienced during the war in obtaining drilling and refining plant, and tonnage to carry it and the additional production of oil. As an example of that he desired to mention that his own Company's production, which in 1917 was only about 1,000,000 tons, would be to-day at

the rate of 5,000,000 tons per annum, had they been able to secure the plant and tonnage necessary to deal with that quantity of oil. Similarly in Mexico, Rumania, Galicia, Venezuela and elsewhere, the production to-day would have been much larger, had it not been for the scarcity of plant and for war conditions.

In the third place the author stated that the new oilfields had not on the whole proved oil as rich in volatile constituents as the old ones. He was at a loss to understand from whence the author gained that impression, and he could assure him that he was quite mistaken, if he was speaking in a broad sense. It was true that some of the oil from the old wells in America and elsewhere, giving only a very small production per well, yielded large percentages of volatile fractions, but, speaking from memory, he thought he was correct in saying that the benzine contents of American petroleum, at any time within the past 10 to 20 years, had not been more than 10 or 12 per cent., whereas the benzine contents of the oil from the Persian oilfields (which he took as an example as they promised to be the biggest in the world) was about 22 per cent. Moreover, the many improvements in refining which had been effected during the past 20 years, and the continually increasing demand for benzine, had resulted in a very much larger proportion of the light fraction of petroleum being extracted now than was the case 20 years ago. What that meant to the future benzine supply of the world could be best realised from the fact that, although the production of benzine from Persian oil in 1917 was only about 120,000 tons, they could to-day, had they the plant to deal with it, supply 1 to 1¼ million tons per annum, *i.e.* the Persian oilfields alone could produce about three times the pre-war consumption of benzine in the United Kingdom, or twice as much as had been consumed during the recent war period for the whole of our military, aviation and civilian requirements, and no less than 6 to 7 times as much as the present total production of benzol. From what he had said it was, he thought, clear that, though there would undoubtedly be a large increase in the consumption of benzine, there was not likely to be any shortage of that commodity for a good many years to come. It was true that the American demand had overtaken the supply of straight-distilled benzine, and that, because it had not paid under war conditions to import benzine from foreign sources, America had had to resort largely to "cracking" heavy oils in order to meet her increased internal demand. But they had not come to that point by a very long way in Eastern oilfields, so much so that they were still forced to burn as fuel under their stills a considerable quantity of that

petroleum product which the author regarded as such a very great scarcity. If and when the time ever came of a real shortage of natural benzine, the supply could be augmented to an enormous extent by "cracking" heavy residuals, as has been done in America, and this supply of cracked benzine would render the introduction of costly substitutes quite impracticable from a commercial point of view. In that connection he might mention that he was asked only a few days ago by a very prominent member of the Institution if they had yet made any arrangements for cracking their heavy oils, to which his reply was: "No, certainly not. It will be time enough to crack our heavy oils when we have found outlets for the whole of the natural benzine we can produce, and we are still a long way off this goal."

He was quite at one with the author in his desire that the motor and allied industries should set up a Research Board or Department to investigate the problems of the different grades of spirit which might be made available for motor-fuel, because the more light that could be thrown on that question the better for the community at large, and the information obtained would certainly be of great value in the event of another war, which, however, he was sure all devoutly trusted might never come. But there was no doubt, he thought, that so long as a sufficient quantity of natural benzine, or even benzine obtained by cracking, could be produced to meet the world's requirements, no substitutes, whether benzol, alcohol or gaseous fuels, could compete with it, because of its much lower cost of production. If and when the demand overtook consumption, and benzine consequently advanced in price, a point would no doubt be reached when it would pay to produce those substitutes, but not before.

The author appeared to think that there might be some possibility of increasing the natural output of benzol beyond the figure reached during the war, when there were special reasons and special inducements, known to everyone, for obtaining the maximum possible production of that grade of fuel. In that, he thought, the author was unduly optimistic. Apart from the fact that gas-works would almost certainly find it necessary to discontinue stripping, in order to bring back the quality of their gas to the pre-war standard, they would probably find it unprofitable to do so when prices went back again to a normal level, and they no longer had a market for toluol, since benzol could never in such circumstances, and at ordinary rates of freight for the transport of benzine, be produced at a price that would compete with the cost of imported benzine. Therefore, he disagreed altogether with

the author's recommendation to benzol producers to set up organisations of their own to compete with benzine. That competition would, of course, be to the advantage of consumers and to the motor allied industries, because it would result in cheaper benzine or benzol, but it would certainly not be to the advantage of the producers, and the author, in suggesting that the interests of the two were the same was, he was afraid, somewhat confusing the issue, unless, possibly, he thought that a benzol producer's interest as the owner of a motor-car might over-ride his business perspicacity. The author had some doubts as to whether the altruism of the benzine producers would go so far as to induce them to forego any profit that might be obtainable by them. He (the President) was quite sure that it would not. Altruism did not exist in business, and he was afraid it could no more be expected that manufacturers should adopt altruistic principles in the matter of selling their wares in the highest market, than that it should be expected that any one else, whatever the wares might be that he had to sell, be it brains, scientific experience, manual labour, or any other attribute possessing a market value, should show a similar spirit of abnegation. But the author suggested that the benzol producers should go a good deal further, and not only forego any profit they might be able to make, but actually sell at a loss, in order that motor users should get their fuel at a low price, since that was the only possible result of entering upon a war of rates with a commodity which costs much less to produce. There was such a thing as the laws of supply and demand, and one of those laws was that so long as the supply of any commodity was in excess of the demand, the price of that commodity must, as long as there was free competition, fall to the level of the cost of production to the man who could produce cheapest, *plus* of course whatever that man might consider a reasonable profit.

He quite agreed with the author's remark that he did not think petroleum people would ever seek to encourage the use of alcohol by mixing it with petrol, because, so long as the latter could be produced cheaper than the former, they certainly would not desire to increase the cost of the fuel which they were offering to motor users, by mixing it with a spirit which would be more costly, and at the same time would not improve, but probably deteriorate, its quality. Therefore, the only way in which the benzol producers could hope to produce benzol at a profit—(and without that it was useless for motor-fuel consumers to regard benzol as a factor in the motor-fuel problem)—was by joining hands with one or other of the benzine distributors, coupled with some arrangement as to

restriction of production of the lower-priced commodity, and thereby availing themselves of the benzine producers' lower cost of distribution, to the mutual benefit of both producers and consumers.

He was afraid he had taken up an unduly long time in his remarks, but as the subject was one on which he thought he might claim to be able to speak with some knowledge, he hoped that what he had said would be helpful in the subsequent discussion.

Sir Boverton Redwood, Bart. (Past-President), said that the author had in the course of his paper invited him to express his views as to the probable future relations between supply and demand in the case of petrol. In connection with that question a delightful address had just been delivered by the President. It was refreshing and reassuring to hear the statements the President had put before them as to the extent to which they might look to Persia, and possibly other parts of the world, for largely-increased supplies of petrol and other products. He had never claimed to be a prophet, and he would be sorry to attempt to express a definite opinion as to the period which must elapse before anything in the nature of a world shortage of petrol was likely to occur, but it was quite evident that, as the author had said, it must be merely a question of time. Whether that time be long or short, it was clear that, whilst as we were relying for our motor-fuel upon petroleum, we were gradually—and it might be more rapidly than was anticipated—exhausting a certain stored amount of material. He could conceive of no greater difficulty than to attempt to estimate the extent to which the growing consumption of petroleum products might expedite the normal rate of exhaustion. It had been considered by high authorities in the United States that some 27 years from the present time Americans would be draining the dregs of their present stores of petroleum. It was quite conceivable that that might be an estimate which was on the liberal side in regard to the length of time, if the development of the uses of petroleum occurred at the rate which was anticipated by a great many experts. Be that as it might, he was quite sure that the President would agree with the author in the statement that it was only a question of time before the situation would have to be faced of a world shortage of petrol, and that in any event it was obviously our duty to do all we could to develop alternative sources of supply of something which would answer the purpose, if for no other reason than to render ourselves as far as possible independent and self-contained in the matter of motor-fuel in respect not only of this country but of the Empire as a whole. It

seemed to him, therefore, that every possible encouragement should be given to the development, not only of the manufacture of industrial alcohol, but also of the obtaining of petroleum or its equivalent from all other possible sources, including the bituminous minerals of which it was known that large deposits existed in this country. He hoped the Government were going to get petroleum by boring. He was sure that if petroleum was obtainable in commercial quantities in this country, Lord Cowdray's staff were going to get it. He did not in the slightest degree grudge the expenditure of a million of our money in that search for oil; he thought it was the right thing, but confessed he would have liked to see a concurrent appropriation of another million to be devoted to the distillation of the bituminous minerals, the existence of which was known, and the richness of which in regard to oil production was a matter that did not admit of doubt. He would have been glad to see something like a race between the two enterprises, and he felt very confident as to which would have won if the distillation and the drilling had been started on equal terms. Now that D.O.R.A. was in process of dethronement, it might be possible to make a start with the distillation of hitherto unused bituminous substances in this country, and something in the nature of a handicap race might be seen, in which after all the one that started first might not win: it might be an illustration of the hare and the tortoise.

The author had referred to the scope of the activities of the Institution. Personally he would scarcely have thought there could have been room for doubt as to the fitness of the Institution to receive, to discuss, to record and generally to deal with communications relating to petroleum in the widest acceptation of the term. Petroleum, according to the Petroleum Acts, meant not only the free oil that was obtained out of the earth, but oil made from coal, schist, shale, peat, and other bituminous substances; and it was perfectly clear that those who founded the Institution intended, in christening it, that the term "petroleum" should be taken in its widest acceptation. He was confident the Council would welcome papers from coke-oven experts, from gas-works authorities and others, on all matters relating to the carbonisation of bituminous substances for the purpose of obtaining hydrocarbons from them.

At the risk of detaining the members unduly, he would like to say a few words in conclusion in reference to the author's remarks on the subject of the recently appointed Government Committee on Alcohol Motor Fuel. If he could conceive it possible that his

taking an active part in the work of that Committee would have the result of alienating the sympathies of the motor manufacturers or motoring community, he would greatly regret having accepted the invitation to take the Chair, but surely, as the author pointed out, he was sufficiently on record during the past 15 years as having very strongly advocated attention being given to the subject of alcohol as a motor fuel. Until recently his exhortations had fallen on deaf ears, but he hoped there was now a prospect of the subject receiving the attention it undoubtedly merited, and those who would take the trouble to study the constitution of the Committee would, he thought, realise that good work was going to be done. In that connection those who had listened to the masterly presentation of the technical aspects of the subject by the lecturer would derive, as he did personally, great satisfaction from the knowledge that Dr. Ormandy was a member of the Committee.

The author had referred to the need for research and had pointed out the grave disadvantages attaching to State-aided research. Personally, he was very hopeful that the Alcohol Motor Fuel Committee would be able to arrange to obtain the whole-hearted co-operation and pecuniary support of the motor trade and the motoring communities, in the manner suggested by the author. It was quite evident that such funds as might be available for the purpose could not be devoted to a better object, and they would be free from the admitted disadvantages attaching to obtaining grants of money from the Government, though he had no doubt that, if help did not come from the direction the author had indicated they would be able to obtain all the pecuniary assistance required through official channels. Personally, however, he deprecated taking advantage of the latter source of the funds which would be needed for research work, unless it was found impossible to obtain them otherwise.

Dr. Blackler thought the author was to be congratulated on placing before the members a paper on a subject of great intrinsic interest and extreme national and international importance. We were living in changing times. The Kaiser had gone, Kaiserism in its broader sense was going, and everyone sincerely hoped that legislation of the order of the Tunis Date and Cultivated Blackberry was going also. He mentioned those matters because the author had laid great stress both on the quantity of motor fuel available and on the question of distribution; and, in order to place before the public the difficulties which might be met in the future, he had suggested that, to create a larger supply of motor-fuel, they should at once forego the present quantities available

from the ordinary petroleum sources. The future of the internal-combustion engine was one which would affect not only the well-being of our own people, but also that of the whole population of the world, and it was for that reason that national and international legislation would eventually have so to move in that direction as to ensure that the well-being of the many should not be affected by the profiteering methods of the few. The author had shown that there was a future for alcohol as a source of motive power, but looked at in the larger sense it would be seen that the fuel-question would eventually resolve itself into determining what mixtures of all available products would prove most suitable for that purpose.

Speaking generally, there was, in his opinion, a very large field for the utilisation of the heavier products of petroleum by the development of some of the well-known cracking processes. Questions of economics would no doubt influence the absolute quantity of motor-fuel produced by that method, but it could undoubtedly be said that as the natural quantities of light petroleum decreased, the spirit produced by cracking would be considerably increased by economic developments of the various processes in question. Benzol had been mentioned, yet there were also vast quantities of toluene which had a boiling point sufficiently low to make it suitable as an ingredient of motor-fuel. During the last 12 months the American Government had undertaken a series of experiments on the cracking of solvent naphtha, and in a series of tests involving well over 1,000,000 gallons of that material an average yield of 75 per cent. of benzine and toluene had been obtained. Motor-spirits produced by cracking were miscible with alcohol within wide limits, and it therefore meant that a motor-spirit containing cracked spirit would also take up a considerable quantity of alcohol.

For the future of the internal-combustion motor industry there were therefore available petrol, pyrogenetic petrol, cracked spirit, alcohol, benzine and toluene, and, with mixtures of those products, the world could consider itself secure, as far as motor-fuel supplies were concerned, for many generations to come. It was difficult to suggest off-hand a means whereby that result could be easily obtained, but, if the various Committees which were dealing with the subject dealt with it from the very broad standpoint, instead of from an alcohol point of view or a benzol point of view, results would be obtained of benefit to all. He personally believed that all attempts to make England independent of all outside sources for the needs of her inhabitants would ultimately mean putting

back the clock of general evolution, and questions such as the motor-fuel question must not be only national but would become international, if the resources of the world were to be utilised in the most economic manner.

Mr. T. C. Thomsen, B.Sc. (Anglo-Mexican Petroleum Co., Ltd.), thought that although the question of a coming world shortage of petroleum was, as Sir Boverton had remarked, merely a matter of time, yet he did not think there would be any serious shortage for many years to come. Further supplies would be forthcoming from the East and from Persia, as the Chairman remarked, and from Mexico the expected production was estimated by American experts to equal, if not surpass, the present day production in the United States.

If the wells already sunk in Mexico were allowed to produce their maximum output (now most of them are temporarily closed or only allowed to produce a fraction of their maximum output) the production would amount to more than half of the U.S.A. output. It was a question of pipelines and refineries, etc., to deal with the output, and the necessary shipping facilities, before the export of oil from Mexico would be very materially increased. The coming large increase in Mexican yield, together with the further supplies from the East, would undoubtedly postpone the time of a world shortage, but those interested in the subject would be well advised to investigate other sources of supply. Owing to the present shortage brought about by the war conditions, the Americans had been obliged to produce large quantities of cracked gasoline and casinghead gasoline in addition to the ordinary grades of spirit. The production of casinghead gasoline in America amounted to approximately 10 per cent. of their total production, and from the enormous supplies of petroleum gas available, it would be possible to produce a much larger amount of casinghead gasoline, these volatile products being particularly suitable for the manufacture of fuel for the aerial traffic engines of the future.

As evidence of the Americans realising the coming world shortage, it was interesting to know that America had arranged to put down experimental plant for distilling shale in one of the worst-situated districts in the middle West, in order to ascertain the manufacturing cost, and to study the possibilities of bringing fuel oil and other products produced from shale within commercial reach. As Sir Boverton Redwood had suggested there was every reason why the same course should be adopted in this country.

Before the shortage of petroleum really became serious, every attention must be given to substitutes, such as alcohol and benzol.

A fair amount of research had been carried out already, and there were certain indications that such properties as vapour-tension, spontaneous-ignition temperature, and other properties of petroleum spirit could be improved or governed by admixture with coal-tar products, such as benzol. It was quite apparent that research was needed, and that any reasonable expense in this direction would be justified. Very large quantities of benzol would be required by our dye industry in the future, which would to a large extent reduce the supply of benzol available for use as an admixture with alcohol or petrol. The distribution of motor-spirit involved a very expensive organisation, and if the future requirements of motor-spirit greatly exceeded the author's estimate, which was not unlikely to be the case, it would mean that the benzol supplies available for motor-fuel would only amount to a comparatively small fraction of the total requirements. An organisation created outside the existing petroleum organisations would probably find it exceedingly difficult to distribute benzol-alcohol or other petrol substitute to the advantage of both the consumers and themselves. It must also be kept in mind that alcohol-benzol mixtures and many other petrol substitutes cannot replace petrol without certain adjustments to the carburettor, air-supply, etc. The case has a somewhat different aspect for such engines as stationary engines or fleets of motor vehicles operating in a certain district, and where arrangements can be made to adjust the engines to suit a particular fuel, and also for a regular supply of such a fuel.

As regards the lubrication troubles which have been experienced during the war, these were entirely due to the use of unsuitable petrol substitutes and motor-spirits containing a large percentage of kerosene, or containing too high a percentage of "heavy-end" products. The less volatile products in the motor-spirit pass the pistons, and mix with the lubricating-oil, and the only remedy so far available for dealing with the trouble in existing engines was to use a heavier-viscosity lubricating-oil than the one which had proved satisfactory when running on good quality motor-spirit, and, furthermore, to change the oil in the crank-case every 2,000 miles or so. It was a curious fact that the heavy-ends in motor-spirit, at the same time as they tended to cause trouble in the crank-case of motor-car engines, evidently had very largely caused carbonisation troubles to disappear. The heavier fractions of petroleum spirits which were akin to the kerosene fractions had a very marked cleansing effect on the pistons and piston rings of motor-car engines, as in fact of all internal-combustion engines. For example, in the large gas-engines using blast furnace or coke-

oven gas in Germany, it was quite a common practice to mix about 25 per cent. of ordinary kerosene with lubricating-oil, the result being that the piston and cylinders kept much cleaner than when lubricating-oil alone was used.

Dr. W. R. Ormandy, in reply, said there was an operation known as trailing the tail of one's coat, putting something down for somebody else to trample on; and he had not attended the meeting, knowing who the Chairman was to be, without realising that the bait would take. The President, as Chairman of one of the largest petroleum Companies, had access to information as to quantities and so on, which were not available to mere ordinary civilians, and he (the author) did not know how he could have found out, except from the Chairman, that last year during the war 200,000 tons of paraffin were used on engines, which had previously not been in use. If he had possessed that information, and had mentioned it in public a few weeks ago he would probably have been locked up. He presumed that the larger portion of that amount had been used for marine work. (**The President** said it had been used for agriculture.) **Dr. Ormandy** said as far as he was aware there had been no great increase in the utilisation or the attempts to utilise kerosene, or what was known as paraffin, in ordinary high-speed internal-combustion engines employed on variable-speed work. Agricultural work, ploughing, for instance, was very similar to marine work; the machine was set, and it proceeded to work under a practically constant load; and under those conditions it was known of old that paraffin could be used very successfully. Those who had had to go to sea in a boat containing a motor-engine driven by paraffin had also probably learned that American kerosene was not the same thing as Russian kerosene; that there was very much more trouble with the one than with the other. Anyhow, it did not cut any ice, as far as he could see, in connection with the argument which he had brought forward, because the matter referred to a new lot of motors that had been introduced. Practically a new industry had been built up during the war, and fuel other than petrol had been found for such motors. It did not alter the position one iota that the growth of the ordinary petrol engine was increasing, and it did not affect the prospect of the fuel supply unless the argument was advanced that there was a possibility that paraffin, because it had been used on a motor-plough successfully, could be used on a variable-speed engine. In the past, experiments had shown that there had been very great difficulty in the utilisation of paraffin.

With regard to the figures that had been given for the volatile

constituent, namely, America 10 and 12 per cent. and Persia 22 per cent., it was not public knowledge, until the President made the statement, that the oil from the Persian oilfields yielded an average of 22 per cent. He could only take such figures as were given by the late Prof. Lewes on the average amount of volatile matter contained in crude petroleum, and as a matter of fact he took his figure from Lewes' book in regard to the total amount of oil.

The President had said a good deal about the fact that benzol could not compete with petrol, owing to the cost of production, but the point he (the author) wished to urge was that the cost of production had nothing to do with the public. The public heard nothing about the cost of the production; all they knew was that they had to buy petrol. It was not said, but it was certainly implied, that the cost of production was quite a serious item, and that the cost of distribution was a much more serious item; in fact, everything was going up, and, until a competitor appeared who could produce in bulk, the relation between the cost of production and the cost at which the article was sold was dependent upon what the producing Companies considered "a reasonable profit." It had been said that the benzol producers would produce at a loss. That would be so if the cost of production of petrol was so very low, and if it was sold at very "reasonable profits." If it could be obtained at that narrow margin, then nobody would want to produce benzol; the public would go on buying petrol at 6d. or 8d. a gallon. As a matter of fact, by-product recovery plants already produced benzol; the coke works had more gas than they could burn in the ovens; and the whole cost of getting it out of the gas was the cost of putting down the plant and running it, and if the cost of benzol went down below a certain price, the production was stopped and it was burned round the coke ovens or under steam boilers. In some cases, particularly in Germany, coke-oven gas was being supplied to the gas-works, and that was already being done in Birmingham. To a certain extent the benzol people were in the same position as the petroleum people; they could not help producing benzol; it was a by-product; and they had to make it and to sell it at the best price they could get for it. At the present time the price they could obtain for it was the competitive price of petrol. It must be interesting to all the members to know that petrol could be produced at the exceedingly low price mentioned by the President, and that benzol could not possibly hope to compete with it. But, as he had already said, what they were interested in was not the cost of production but the sale price, and it was because they wanted to have some control of the sale

price that he advocated the development of the production of alcohol, because it was known that that was made from a product which grew from year to year, and that its cost of manufacture was a more or less stable quantity. Although the price might be, say, 1s. 6d. a gallon delivered to the user, they knew that was a fixed quantity, and that they were not at the beck and call of a firm or a number of firms that could sell to-day at 6d., because the cost of production was cheap, and to-morrow at 1s. 6d., because distribution was dear. Sir Boverton Redwood had pointed out that alcohol deserved to be recognised because sooner or later there must be a shortage of petrol, and that it was better to start now than to wait until the shortage commenced. It was just as well to be ready. Again, there was the advantage that if a reasonable quantity was being produced it tended to keep the cost of production of the other article low. There were also the other aspects, such as the agricultural, which were bound to be of very great moment, and which of necessity ran concurrently with the production of alcohol.

When he used the word "benzol" as a motor-fuel, he meant the mixture of benzol and toluol. The separation only took place during the war for Government requirements. When one spoke of benzol as a motor-fuel one referred to the product consisting of a mixture of benzol and toluol (and possibly a small amount of the xylol) coming up to the grade of what was known as light solvent naphtha.

That Mexico could produce 50 per cent. of the amount produced by the United States did not appear to him to affect the issue to any serious degree. If it was a fact that America, which was the largest producer, was already on the verge of requiring more spirit than she could produce, and might even become an importer, a production of 50 per cent. more, when all the rest of the world was increasing its demand, would affect the position only for a time. If American demands were growing at such an enormous rate, it was highly probable that before long America would be an importer, and would be competing in the world's markets, so that an increase of 50 per cent. in Mexico would rapidly be swallowed.

On the whole he felt that the arguments that had been brought forward rather pointed to the desirability and the advisability of developing alcohol as a motor-fuel. It might be the case that a certain number of years would elapse before there was really a world shortage, but it must not be forgotten that alcohol at any rate could be produced within the limits of our own Empire. If the members could imagine that there was exhibited on the wall a map

of Africa having an area of 25 sq. ft., and would remember that one sq. in. of that under maize would produce enough alcohol to displace all the petrol used in this country in any one year, they would appreciate the strength of his argument; it did not seem much when it was looked at from that point of view. If motor users, and makers who were at the present time building up their industry entirely on a product which was absolutely out of their control and under the control of two or three groups of people, would realise the possibilities of the production of alcohol on an industrial scale, with the knowledge that a fuel was being produced partly by their own efforts, which was under their own control, it would be in every way desirable.

In conclusion, he desired to express his thanks to the President for dealing with the subject in such an admirable and tactful manner. It was with some diffidence that he argued a point of view which must be absolutely opposed to the policy which the President must advocate as the Chairman of a very large petroleum Company.

The President, in moving a hearty vote of thanks to the author for his excellent paper, said he only desired to say that, although he was in full sympathy with the desire that the question of substitutes for petroleum should be studied, yet it was, in his opinion, to a very great extent an academic one at the present time, but one did not know what exigencies might occur. For instance, he had lately been driven to lay in supplies of wood and peat, although their cost was about six times that of coal for the same equivalent of heat, and something of the same sort might occur in the future, which would lead him to use alcohol or other substitutes in place of petrol, although he sincerely hoped, for the sake of his product, that this would not be the case. With regard to the high price of petrol the author was probably not aware that practically the whole of the profits at present went into the pocket of the State, so that in that respect the petroleum people were not the sinners they were represented to be.

The resolution of thanks having been carried by acclamation, the meeting terminated.

On the Relative Importance of Oil Seepages.

By W. H. Dalton, F.G.S.

As eruptions indicate disease, whether trivial or serious, so emanations of oil or gas demonstrate the presence of at least some form of hydrocarbon which may by quantity or quality be of commercial value, although incapable of being gauged in either respect by the natural escape. Evaporation of volatile ingredients, and oxidation of others, effected at some depth below the surface, leave the original character of the oil undeterminable from examination of that superficially discharged, except as regards its major classification as asphaltic or paraffinous.

Seepages may be determined in regard to their point of emanation by several conditions of geological structure, widely different in regard to their promise of valuable yield: (1) crevices in impervious strata on the crests of anticlinal folds; (2) outcrops of pervious beds more or less charged with oil or gas; (3) fault fractures; (4) joints and vesicles in volcanic rocks.

The first category affords of course the most valuable evidence, or rather the most favourable from the point of view of productivity. For although anticlinal flexures, even in a petroliferous series, do not necessarily ensure a yield of commercial value, which depends rather upon the character of the rock in which the oil has accumulated, yet the coexistence of suitable rock and suitable structure is a combination that leaves little to be desired. The crevices may result from rupture, as the strained flexure is relieved from the counterbalancing pressure of overlying beds in the course of denudation. In some cases again, oil-charged rocks lie within the depth attainable by crevices due to desiccation of clay in time of drought, and the petroleum exudes only in summer. Where the discharge of oil is too feeble, from its viscidity or from the narrowness of the passages, to make its upward way to the surface without other assistance, it may be displaced by water percolating downwards. The salinity of the water associated with petroleum serves as a criterion of its origin, that from superficial sources being almost invariably less saline than that native to the oil-bearing rock.

Outcrop-seepages are of somewhat less importance in respect of promise, as they may be the last leakages of exhausted reservoirs. On the other hand, asphaltic oil may in its desiccation tend to seal the pores of the rock, and stop further escape, so that asphalt-flows

are by no means despicable evidence. It must also be borne in mind that in regions of slight dip, minute variations of the disturbance, or even local peculiarities of deposition, may afford opportunity for accumulation of oil, protected by such structure from escape at the outcrop. But any active flow of water, under accumulation of hydrostatic pressure, will have the greater effect in such cases in the subterranean transport of oil.

Seepages along faults are merely evidence that at some unknown depth, oil-bearing beds are traversed by the fractures, the line of dislocation not having completely closed. Faults in consolidated rocks may generally be regarded as detrimental to prospects of rich yield, as facilitating escape of oil, though, in some rare instances, such escape may be into a rock better fitted for storage than the original position of the oil. In softer deposits, faults are probably unaccompanied by open fissures, unless of momentary existence under earthquake-strain, and not admitting of any appreciable migration of oil, should stores of such be within the range of the fracture.

The fourth category is hardly worth mention except as a warning against hasty conclusion. The rare production of some form of hydrocarbon by chemical changes cannot rightly be classed as seepage, in respect of its deep-seated cause, and extremely limited quantity, so as never to emanate on the surface. Such are the occasional outbursts of combustible gas in vein-mining, and the occurrence of traces of bituminous material in metalliferous lodes: they are interesting and instructive phenomena, but of purely academic importance.

Scarcely less trivial as a rule is the occurrence of oil or gas in the joints and interspaces of volcanic rocks, which have traversed strata containing bituminous matter, and either separated hydrocarbons from it by a distillatory process, or absorbed fluids already formed into their crystalline interspaces and contraction-crevices during their age-long refrigeration. Instances of the first of these processes are numerous, those of South Africa, Sicily and Scotland being typical, whilst parts of northern Mexico offer examples of the tapping of deep-seated petroleum by volcanic necks, in which the cooling process is still not wholly complete. Richly productive as some of the wells here have proved, it is nevertheless an exceptional occurrence, vulcanicity generally being detrimental to petroleum and coal alike. The flames seen in the eruptions of Etna are evidently due to the combustion of hydrocarbon gases as the internal heat reaches successive portions of the oil-charged rocks of Sicily, whilst the cooled products of previous discharges

act as receivers for paraffin wax, asphalt, and liquid petroleum. The Lipari Islands, north of Sicily, wholly volcanic in character as exposed at the surface, if not throughout their mass above sea-level, were for centuries a source of asphalt to the Carthaginians, whilst traces of vaseline or kindred paraffins have been found occluded in the rapidly-cooled obsidian of the same locality, and the vesicular lavas of the Etnean mass are occasionally charged (like the intrusive rocks of the Lothian oil-shale fields) with paraffin wax and various forms of fluid petroleum.

It is evident, therefore, that in all practically-unexplored regions, seepages of oil may be evidence of a wide range in importance. Careful investigation should be made wherever practicable as to the geological condition of their occurrence, and in cases where access is difficult or impossible, close questioning should be substituted for examination of the spot, with a view to elicit, if it may be, the salient facts relating to the exudations.

The foregoing hints may serve to indicate points to be specially inquired into.